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Appleton, Wisconsin

AN INVESTIGATION OF LINERBOARD CRACKING

Project 1108-29

A Summary Report

to

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

December 22, 1966

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

AN INVESTIGATION OF LINERBOARD CRACKING

SUMMARY

This concluding report summarizes work relative to the nature, cause, and evaluation of the cracking (rupture) of the double-face liner in panel score-line areas. The interrelated objectives of the study have been to (a) analyze the nature and magnitude of the strains imposed on the double-face liner when folded as combined board, and (b) to establish methods for determining the cracking potential of linerboard.

With regard to the first objective, a qualitative analysis based on photographs and mechanics indicates that:

1. During folding the single-face liner forms an anvil about which the double-face liner is stretched and bent.

2. The significant types of strain induced in the double-face liner are:

   (a) Direct tension strains

   (b) Bending strains

   (c) Shear strains

3. Cracking occurs when the tensile strains due to bending and direct tension in the outer plies of the double-face liner exceed the allowable stretch in those plies. The tensile load-elongation characteristics of the outer plies are of importance as a consequence.

Based on these considerations, a tester was developed which stretches and bends a linerboard strip over anvils of known diameter. Using the tester it was found that,

1. Good correlations between linerboard cracking angle and the degree of combined board cracking were obtained – particularly for the 69- and 90-pound grade weights. Because the correlations were less satisfactory for 42-lb. liner grade weights, the tester is not recommended for the evaluation of lower weight boards such as 42-lb. liner.

2. The degree of combined board cracking could be linearly related to relative humidity at time of folding using probability coordinates. This means that estimates of combined board cracking severity can be easily made for various humidities at time of folding.

3. The tester failed to properly rank the only 90-lb. laminated liner-board sample included in the study – perhaps because the transverse bending and shear characteristics of the laminated board may be expected to differ significantly from "unlaminated" boards. This appears to be one limitation on its use.

The Institute will arrange to manufacture cracking testers for those mills interested in using it. It should be kept in mind, however, that a number of variables associated with the design and operation of the tester have not been studied in detail. Modifications in design or test procedure may prove desirable in the future.

While it was hoped to study in depth the effect of various board manufacturing variables on linerboard cracking, only a limited amount of data was obtained in this area. The results suggested that higher hardwood contents, overdrying, or surface applications of starch would increase cracking.

INTRODUCTION

A recurrent problem in the manufacture and use of corrugated boxes is rupture or cracking of the double-face liner along the score when the board is folded or subsequently stored in a very dry atmosphere after folding. It is usually a seasonal problem with most difficulties being encountered during winter when inside humidities drop to low levels. Cracking is usually most severe for vertical scorelines where the score is oriented at 90° to the machine direction of the liner — because the strains set up during folding coincide with the direction of least stretch.

During the past several years the Institute carried out an investigation directed toward (a) studying the nature and magnitude of the strains imposed on the double-face liner when folded, and (b) studying methods for determining the cracking potential of linerboard.

Ten interim reports (1-10) were prepared during the course of the study. These reports may be found in Appendix I — with the exception of Reports 6 and 10. The latter were review reports and much of their content is duplicated herein.

The results obtained during the study are summarized briefly in the main text of this report. Test procedures and data may be found in the individual reports.

MATERIALS

Butt rolls of commercial linerboard were obtained from members of the F.K.I. in 42-, 69-, and 90-lb. grade weights. The physical characteristics of the boards are summarized in Reports 2, 3, and 4, respectively, for the 90-, 69-, and 42-lb. grade weights.

GENERAL TEST PROCEDURES

The general procedures employed in the study are described in this section. More detailed discussions of procedures may be found in the individual reports.

DOUBLE FACING AND SCORING

Double-faced board was made by hand gluing sheets of the linerboard to standardized single-faced boards made on the Institute's corrugator. Twenty-six pound semichemical mediums were used in all phases except in Report 7 where the effect of medium stiffness on combined board cracking was studied. Either 90- or 42-lb. single-face liners were employed.

The combined boards were scored using a "V" male and flat steel female scoring wheels. A scoring clearance equal to the sum of the liner and medium calipers plus 0.005 inch was used. In general, three 11-inch long scores were inserted in each of five 18-inch long sheets for each board combination to give a total of 165 inches of scoreline for cracking evaluation.

FOLDING

Before folding, a flat black paint (Rust-Oleum No. 412) was sprayed along the scored area from a distance of about 12 inches so as to obtain complete coverage of the test area. The purpose of the paint was to facilitate measurement of the degree of cracking. A number of other inks and paints were also considered; however, none appeared to have any outstanding advantage over the Rust-Oleum No. 412.

After drying the paint, the board was conditioned in the test atmosphere and folded. The cumulative length of severe cracks was then measured.

LINERBOARD CRACKING TEST

In general, ten specimens for each linerboard sample were evaluated in each test atmosphere with the fold line at right angles to the machine direction. As in the case of the combined board samples, a spray coating of Rust-Oleum No. 412 was applied to increase crack visibility. In most instances the rupture angle associated with the first appearance of a crack in the liner surface was measured.

DISCUSSION OF RESULTS

COMBINED BOARD FOLDING MECHANISM

The photographs in Fig. 1 and 2 illustrate the sequence of events which occur when combined board is folded and are similar to those shown by McKee and Altmann (11). In the early stages of folding, the inside liner buckles inward and then is folded back on itself. By the time the board has been folded about 135°, the inside liner forms an anvil about which the double-face liner is stretched and bent. Thus, an impasse is encountered since the outer liner is prevented from displacing inwardly by the single-face liner. As a result the torque required to fold the board rapidly increases near 135° as the single-face liner is distorted or displaced sufficiently to permit completion of the fold. If the strain induced in the double-face liner during the process becomes too great, cracking of the double-face liner will occur.

A compression-shear distortion of the double-face liner near areas of sharp curvature is often observed with heavyweight liners. This type of distortion is evident in Fig. 2 near the apex of the fold. Other examples are shown in Fig. 3.

In general, the magnitude of the strains induced in the double-face liner, and hence the likelihood of cracking will be dependent on

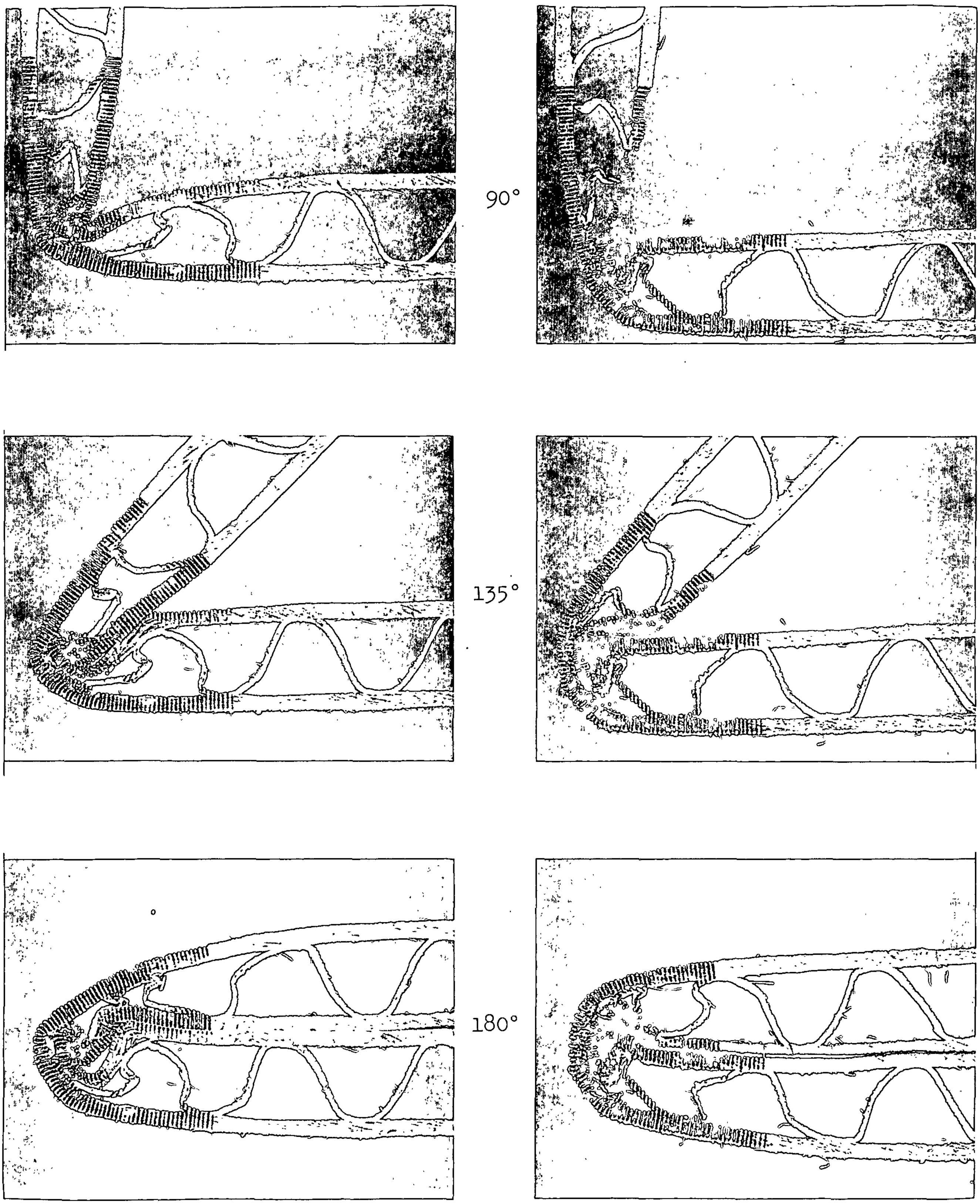
(1) the properties of the double-face liner,

(2) the stiffness of the single-face liner and medium in the scored area,

(3) score wheel profile and clearance,

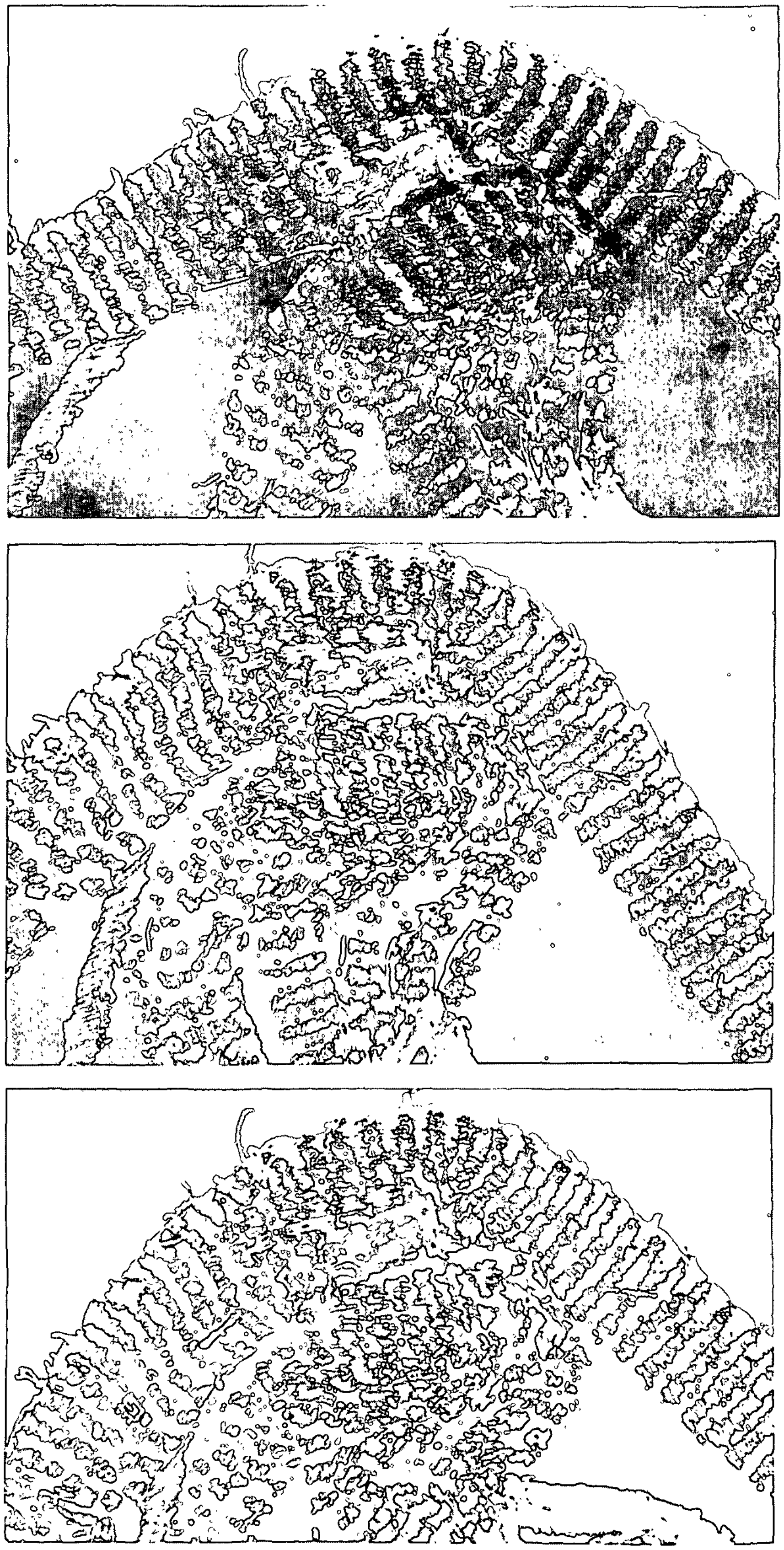
(4) moisture content at time of scoring and folding, and

(5) flute.



Specimen 1 Specimen 2

Figure 1. Stages in Combined Board Folding – About 3X Magnification

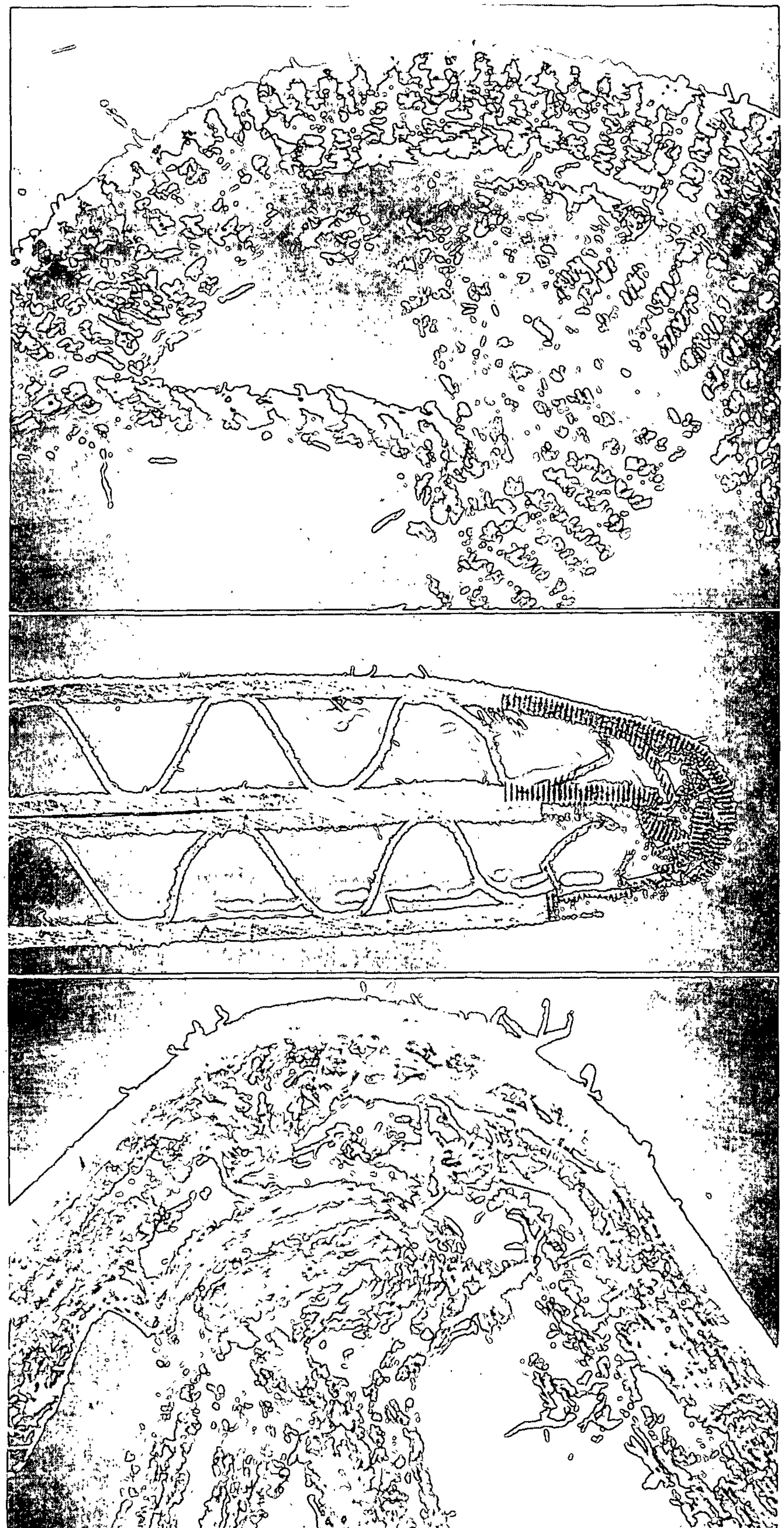


90°

135°

180°

Figure 2. Stages in Combined Board Folding — About 20X Magnification



Sample 288 -
350 Lb. Series
Board

20X
90° Fold

3X
180° Fold

Sample 2503 -
350 Lb. Series
Board

20X
90° Fold

Figure 3. Compression-Shear Distortion and Delamination

For example, a heavyweight single-face liner will form a stiff anvil which will not readily deform. This will stress the double-face liner more highly and result in an increased likelihood of cracking. As another example, low moisture contents at time of folding markedly increase the likelihood of cracking because the allowable stretch of linerboard decreases as the moisture content is lowered. These factors will be discussed in greater detail in later pages.

During folding the significant types of stresses induced in the double-face liner are believed to be

1. bending, σ
2. shear, τ
3. uniform tension, σ

These stresses (σ or τ) will vary across the thickness (h) of the double-face liner as shown in Fig. 4.

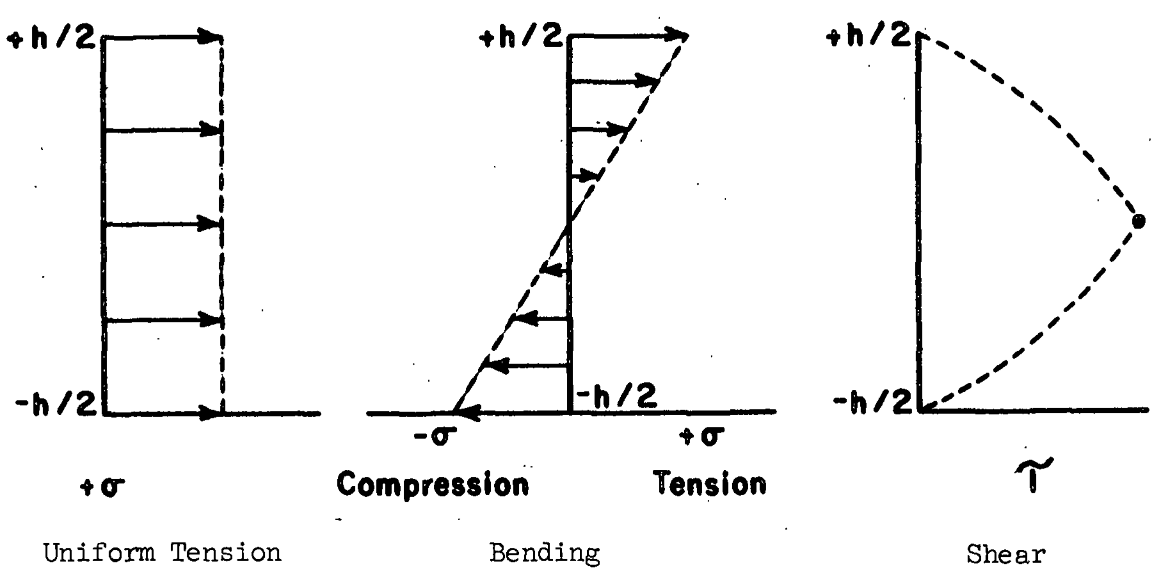


Figure 4. Types of Stresses Induced on Double-Face Liner

The uniform tension strains are induced in the double-face liner due to the resistance of the single-face liner and medium to compression. The direct tension stresses will be approximately constant across the liner thickness.

The bending and shear stresses are associated with bending of the double-face liner about the anvil made by the single-face liner. The maximum tension stress due to bending occurs on the outside surface of the fold and is directly proportional to the thickness and inversely proportional to the radius of the curvature at any given angle of fold. In general, the radius of curvature near 180° fold cannot be less than the thickness of the single-face liner plus medium; it will usually be greater because the single-face liner spreads open due to compression buckling or failure. The double-face liner is not smoothly curved around the single-face liner and will often exhibit two or three zones of relatively great curvature (small radius) – see Fig. 1 and 3. These may occur where the shear and compression strength of the double-face liner is exceeded.

Curvature measurements from photographs similar to those in Fig. 2 and 3 were made by determining the approximate radius of the outside surface in the zones of greatest curvature. The results are shown in Table I. As would be expected, the radii increase with board weight. This possibly suggests that different radii should be used in the linerboard cracking tester for the various board weights.

For a rectangular section, the shear stresses follow a parabolic distribution, varying from zero at either surface to a maximum at the neutral axis. The presence of shear stresses is indicated in Fig. 2 and 3 where the inked lines across the thickness have been distorted. The presence of shear strains should reduce the amount of bending strain developed in the double-face liner as it forms around the single-face liner anvil. Therefore, an easily delaminated, low-shear strength board would be expected to fold to a given curvature with less likelihood of fracturing than a board with high shear strength.

TABLE I

DOUBLE-FACE LINER CURVATURE ON FOLDED COMBINED BOARD SPECIMENS

Sample	Series	Fold Angle	Radius of Curvature[b] Outer	Radius of Curvature[b] Inner[c]
64-70288	350	180	0.146	0.121
2503	350	180	0.101	0.076
2503	350	180	0.101	0.076
2503[a]	350	180	0.082	0.057
Av.			0.108	0.082
64-70286	275	180	0.077	0.057
2505	275	180	0.082	0.062
2505	275	180	0.062	0.054
Av.			0.074	0.054
2406	200	180	0.050	0.037
64-70288	350	90	0.163	0.138

[a] Cracked.
[b] Based on zone of minimum radii.
[c] Calculated by subtracting 0.013, 0.020, and 0.025 from outer radius for 200, 275, and 350-lb. series boards, respectively.

Cracking occurs when the tensile strains in the outer plies exceed the allowable stretch in those plies. As an illustration, among the linerboards evaluated during the study were two boards laminated with extensible outer plies. These 90-lb. linerboards exhibited no combined board cracking — even when the humidity was lowered to 10% whereas conventional 90-lb. liners cracked severely (30-100%). This emphasizes the importance of high stretch in the outer plies.

These extensible laminated linerboards exhibited a machine-direction stretch of 2% – not materially higher than a number of other boards. This highlights the fact that conventional stretch measurements will not necessarily predict cracking performance. The conventional stretch measurement is influenced by the response of the sheet over its entire thickness whereas cracking is believed to be more influenced by the surface ply characteristics.

DESIGN AND CONSTRUCTION OF LINER CRACKING TESTER

Based on this analysis of the folding operation and past experiences, a foldability tester was constructed which folds a strip of linerboard over an anvil of small diameter – see Fig. 5. A simplified diagram of the action taking place is shown in Fig. 6. The test strip is clamped at the ends; therefore, the outer surface of the liner is subjected to tensile strains arising from elongation of the neutral axis and to tensile strains arising from flexure of the strip.

From a more simplified standpoint, the strain occurring in the linerboard is schematically illustrated in Fig. 6. As shown in the figure, the change in length (ΔL) of the top surface of the specimen would be as follows:

$$\Delta L = \theta t \tag{1}$$

where θ = angle of rotation

and t = thickness

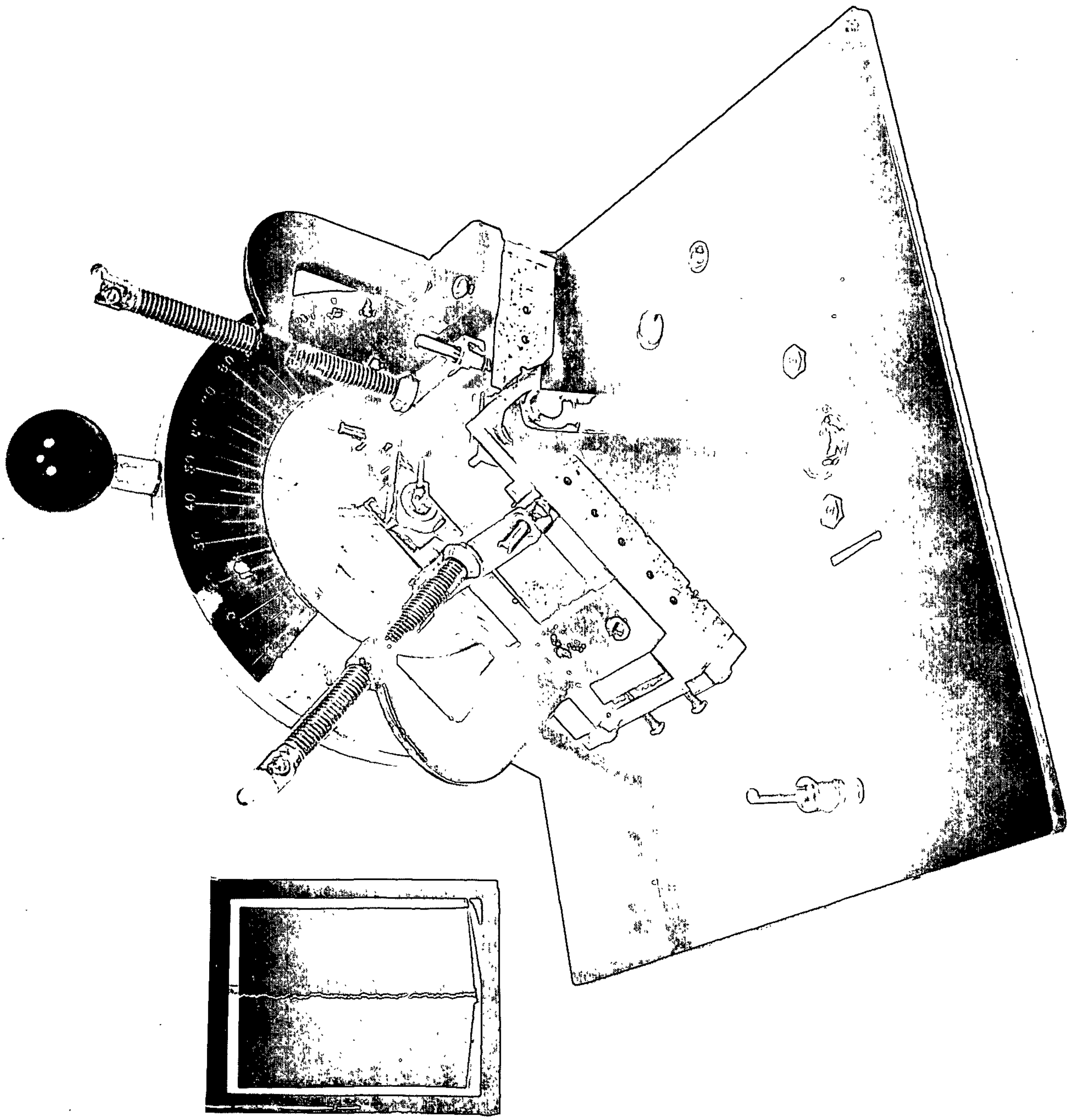


Figure 5. Linerboard Cracking Tester

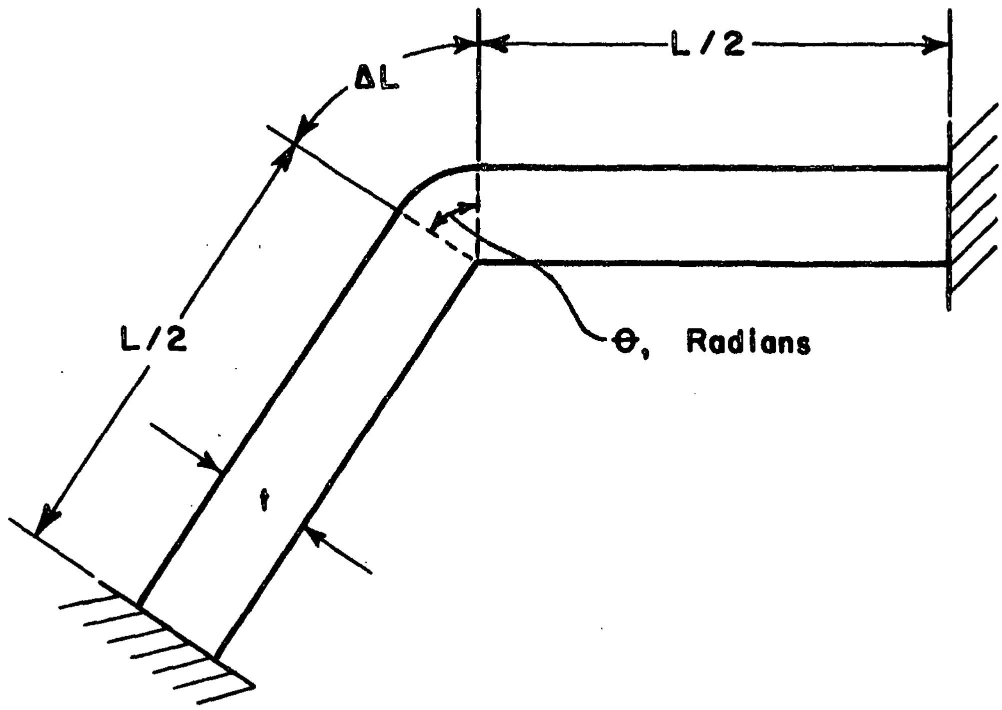


Figure 6. Schematic Diagram of Action Taking Place on Linerboard Tester

If it is assumed that the maximum strain (ϵ) in the outer surface is concentrated in a small zone near the center of the bent area, then the strain may be represented as follows:

$$\epsilon = k\theta t \qquad (2)$$

where $\underline{k}$ = constant associated with initial length of highly strained zone.

Then, when the maximum stretch ($\epsilon_{\underline{f}}$) in the outer surface is exceeded, rupture will occur, i.e.,

$$\theta_f \doteq \epsilon_f / kt \qquad (3)$$

where $\theta_{\underline{f}}$ = angle of rotation when rupture occurs.

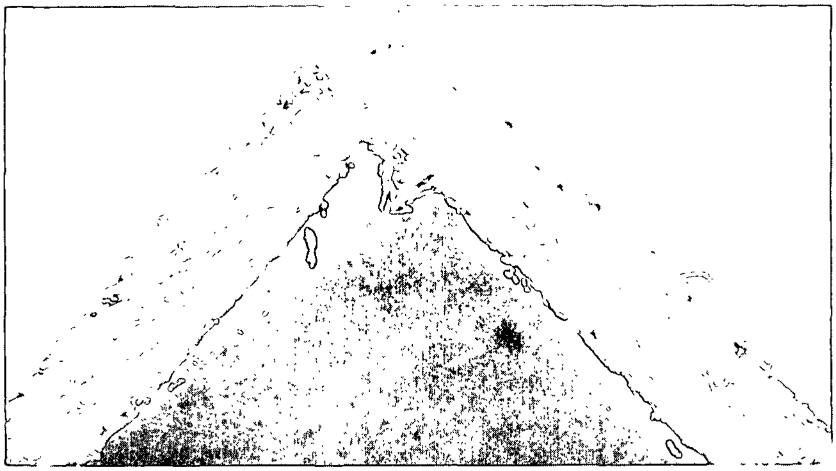
Equation (3) is in agreement with the general observations that the thicker the sheet or the lower the allowable stretch in the outside surface layers, the lower will be the angle of fold required to produce fracture.

The specimen size used was 1.5 inches wide by 6 or more inches long with the long direction parallel to the machine direction. In this study, a paint coating (Rust-Oleum flat black No. 412) was sprayed in the test area to facilitate detection of cracking. Various end points may be used; however, the angle associated with the first observation of cracking appeared to call for less operator judgment and also correlated well with combined board cracking. Edge view photographs of typical specimens removed from the tester and refolded to near the critical rupture angle are shown in Fig. 7.

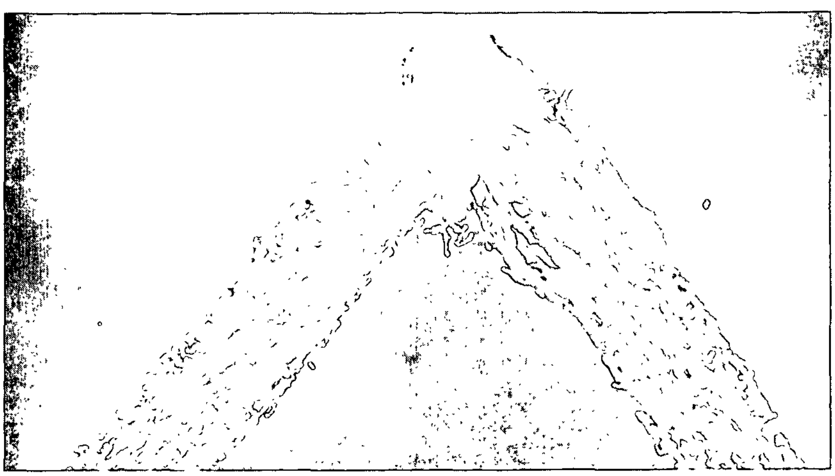
RELATIONSHIP BETWEEN COMBINED BOARD CRACKING AND LINER CRACKING TESTER RESULTS

Extensive studies of the relationships between liner cracking tester results and combined board cracking were made. The results were summarized in Reports 1 through 5. The more interesting relationships are illustrated in Fig. 8 for 69- and 90-lb. liners using probability coordinates. In general, good correlations were obtained for these two grades indicating that reasonably good predictions of combined board cracking can be made with the liner tester. This should permit use of the tester to evaluate linerboards in terms of their folding potential.

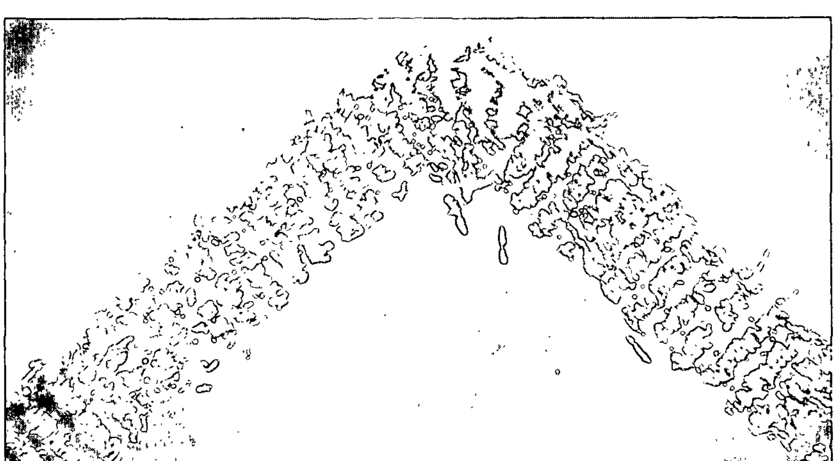
The regression lines shown in Fig. 8 correspond to Equations (9) and (10) in Report 4 and are strictly applicable only for the experimental conditions employed. It is anticipated that a number of separate regression lines would be obtained as flute size, scoring wheel profile or board construction (single-face liner or medium stiffness) is varied. For example, if a scoring wheel profile



Specimen 1 — 90-Lb. Kraft



Specimen 2 — 90-Lb. Kraft



Specimen 3 — 90-Lb. Kraft

Figure 7. Linerboard Cracking Tester Specimens — About 20X Magnification

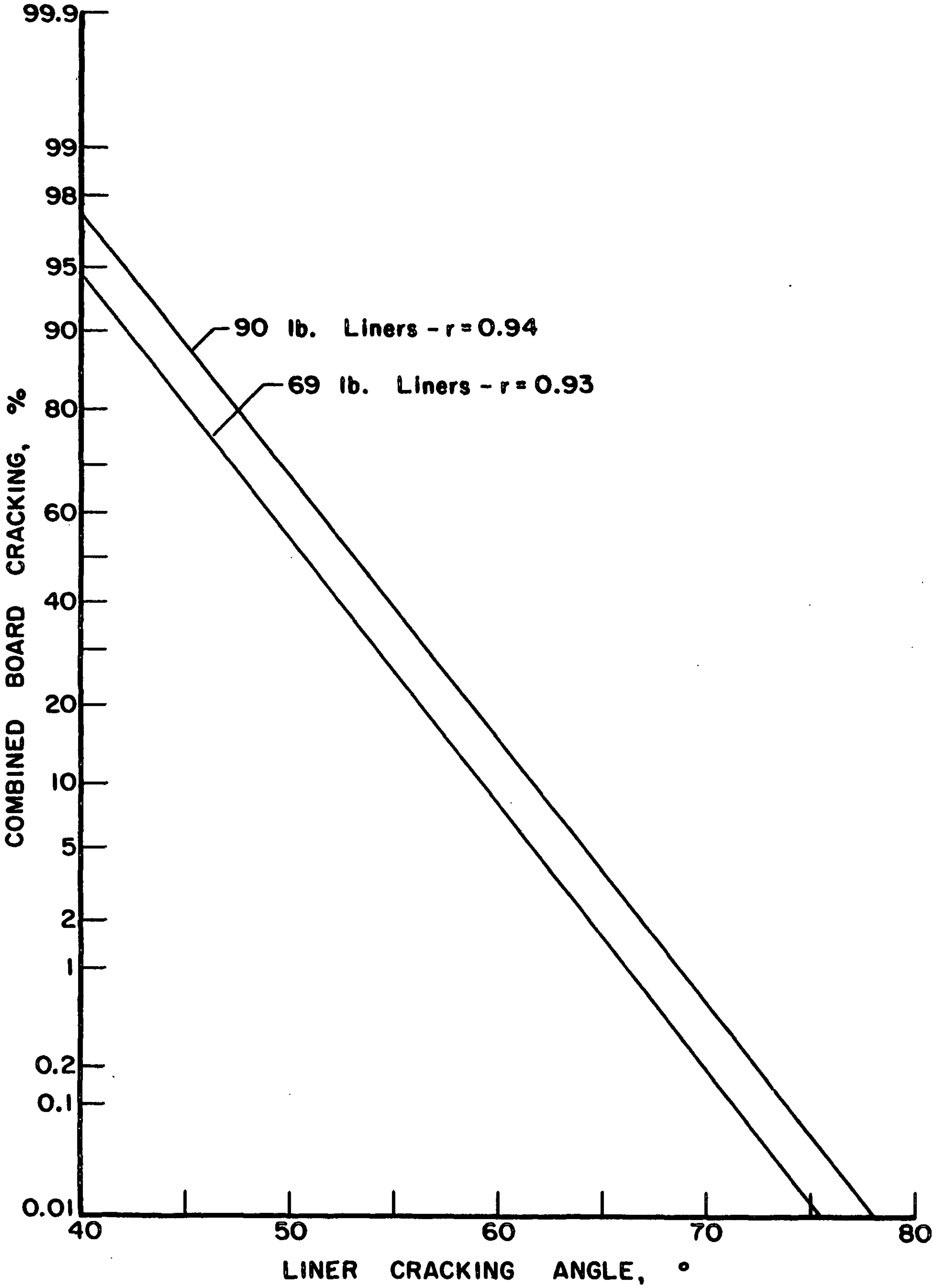


Figure 8. Relationship Between Combined Board Cracking and the Liner Cracking Angle

is used which results in lower folding stresses in the double-face liner than the "V" male and flat steel female wheels used in this study, a displacement of the regression lines to lower degrees of combined board cracking for the same cracking angle would be expected. However, it is felt that the use of other conditions would probably result in parallel shifts of the regression lines. Therefore, predictions of combined board cracking based on Fig. 8 should hold on a relative basis.

The correlations of liner cracking angle vs. combined board cracking were less satisfactory with 42-lb. liners. Therefore, the tester is not recommended for evaluating the lower weight linerboard grades.

RELATIONSHIP BETWEEN COMBINED BOARD CRACKING AND RELATIVE HUMIDITY AT TIME OF FOLDING

Generalized relationships between combined board cracking and R.H. are shown in Fig. 9 for 90-lb. liners. In general, on arithmetic probability coordinates, the degree of cracking was linearly related to R.H. and the slopes of the regression lines were nearly parallel for all samples within a grade weight. In fact, rather similar slopes were obtained for 42-, 69-, and 90-lb. liners. Therefore, the lines shown in Fig. 9 may also be used for 42- and 69-lb. liner constructions with little error if it is kept in mind that the "average" degree of cracking decreases substantially as liner weight is decreased.

In the figure the solid line is the average line for all 90-lb. liner samples evaluated. The dashed lines were drawn parallel to the solid line so as to pass through percentage cracking values of 0.1, 0.5, 1%, etc. at 30% R.H.

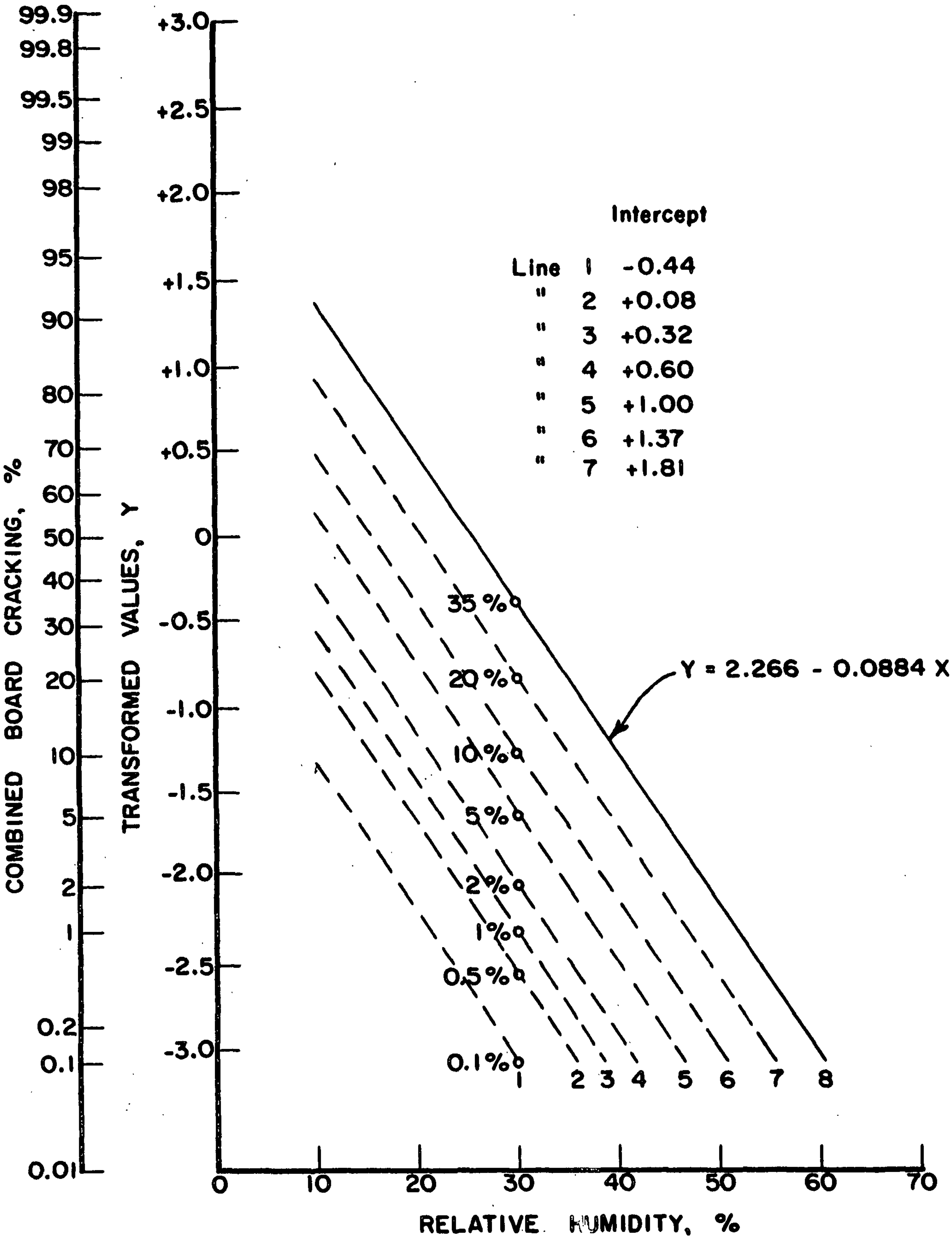


Figure 9. Generalized Relationship Between Combined Board Cracking and R.H. at Time of Folding for 90-lb. Liners

In combination with Fig. 8, these relationships can be used in a number of ways. For example:

1. If it is known that board made in a given way exhibited a low degree of cracking – say, 0.1% – at 30% R.H. it is possible to make predictions of the degree of cracking at other humidity levels using Fig. 9. In this case, at 10% R.H. the expected degree of cracking would be near 8%.

2. If a liner cracking angle of 70° is obtained at 30% R.H., this would correspond to about 0.5% cracking for a 90-lb. liner sample in Fig. 8 – assuming A-flute construction, "average" flat crush, "V" male and flat female scoring profile, etc.

3. A level of 0.5% cracking at 30% R.H. is on the second curve from the bottom in Fig. 9. It may then be estimated that the degree of combined board cracking may rise to as high as 20% or more if the humidity at time of folding falls to 10% R.H.

The overall regression lines for the 69-lb. and 90-lb. liner samples are shown in Fig. 10. In general, the vertical distance between the regression lines represents the average difference in degree of cracking for the two liner grades for the experimental conditions used in these studies. These differences would be as follows:

	Percent Combined Board Cracking	
R.H., %	69-Lb. D.F. Liner	90-Lb. D.F. Liner
10	66	92
20	32	69
30	9	35
40	1.5	10
50	0.12	1.6

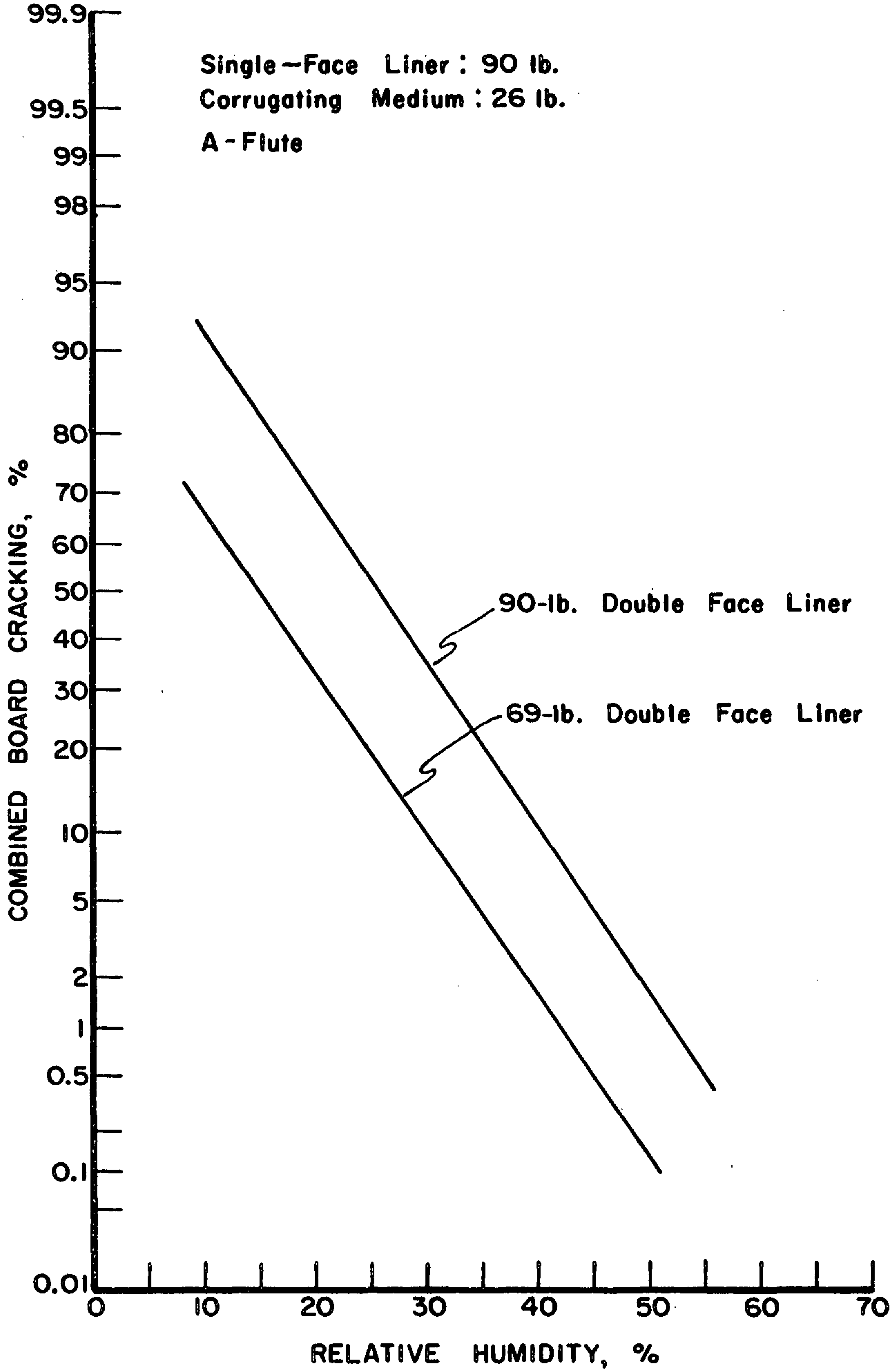


Figure 10. Comparison of Average Regression Equations for Relationship Between Combined Board Cracking and R.H. at Time of Folding

Since both grade weight liners were fabricated into combined board using a 90-lb. single-face liner, it may be expected that the "average" 275-lb. series board with 69-lb. single- and double-face liners would exhibit less cracking than noted above.

EFFECT OF SINGLE-FACE LINER WEIGHT AND MEDIUM STIFFNESS ON COMBINED BOARD CRACKING

In the early phases of the study, major attention was focused on the development of a linerboard tester which would correlate with degree of combined board cracking. To establish the degree of correlation it was necessary to vary only the double-face liner in fabricating the combined board. Thus, for a given grade weight of liner, the single-face liner and medium were held constant. It was recognized, however, that the degree of combined board cracking would be dependent to some extent on the characteristics of the single-face liner and medium as well as the scoring wheel profile and clearance. To illustrate this dependence, a limited study was conducted in which 69- and 90-lb. double-face liners were combined with 42-, 69-, and 90-lb. single-face liners using four mediums ranging in flat crush from about 28 to about 55 p.s.i.

The results obtained are tabulated in Table II and the 10% R.H. results are shown in Fig. 11 and 12. Referring to the table or Fig. 11, it may be noted that the degree of cracking increased with single-face liner weight as expected. The most substantial increases in cracking were obtained in going from 69- to 90-lb. single-face liner while only small differences in cracking tended to be obtained in going from 42- to 69-lb. single-face liners. As the single-face liner increases in weight, its compression resistance — e.g., ring crush — increases and it behaves as a more rigid anvil. Because it does not deform as readily, greater stresses are developed in the double-face liner and more cracking results.

TABLE II

EFFECT OF SINGLE-FACE LINER WEIGHT AND MEDIUM STIFFNESS ON COMBINED BOARD CRACKING

Liner Wt., lb./M ft.^{2}		Medium Flat Crush, p.s.i.	Combined Board Cracking, %		
D.F.	S.F.		10% R.H.	20% R.H.	30% R.H.
90	90	27.9	59.8	46.1	12.4
		31.4	38.0	15.5	6.5
		38.6	26.5	14.5	5.5
		50.4	26.4	7.2	3.9
			37.7	20.8	7.1
90	69	29.4	35.8	4.5	4.5
		30.3	28.0	14.5	4.6
		39.8	15.4	13.2	1.4
		52.4	14.4	11.8	1.0
			23.4	11.0	2.9
90	42	30.7	30.0	18.8	2.2
		31.1	22.6	11.9	6.9
		39.2	31.1	5.4	1.1
		58.5	13.4	2.0	0.9
			24.3	9.5	2.8
69	90	30.6	29.5	24.6	3.9
		31.3	13.7	9.1	1.5
		39.4	4.8	1.8	0.8
		54.5	5.7	0.9	1.0
			13.4	9.1	1.8
69	69	30.0	6.3	1.6	0.2
		31.0	2.3	0.2	0.0
		39.1	1.9	0.8	0.0
		55.5	0.5	0.0	0.0
			2.8	0.6	0.1
69	42	28.6	4.7	4.1	1.1
		31.7	9.2	2.4	0.2
		37.7	2.5	0.3	0.2
		56.4	0.2	0.3	0.0
			4.2	1.8	0.4

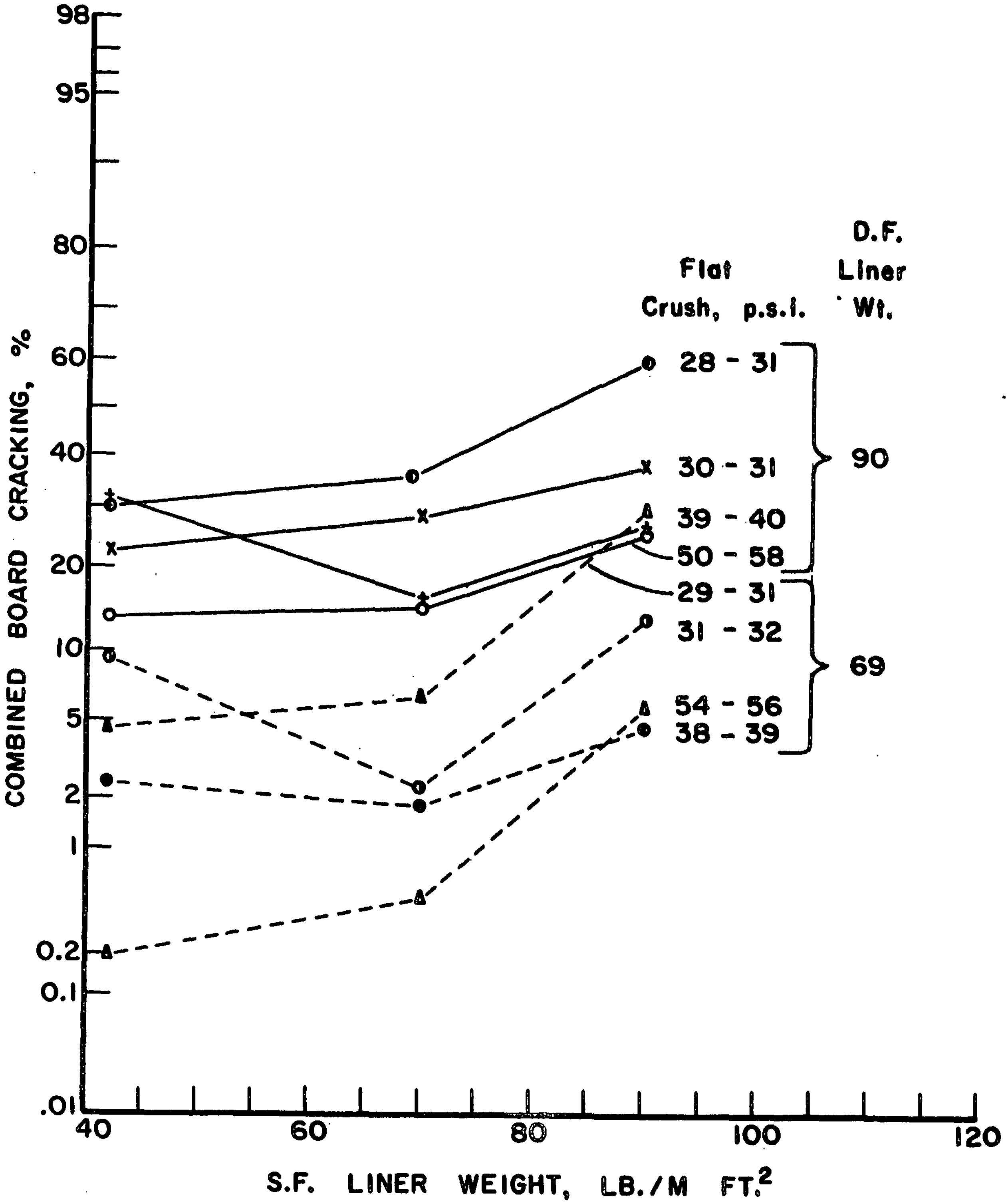


Figure 11. Effect of Single-Face Liner Weight on Combined Board Cracking at 10% R.H.

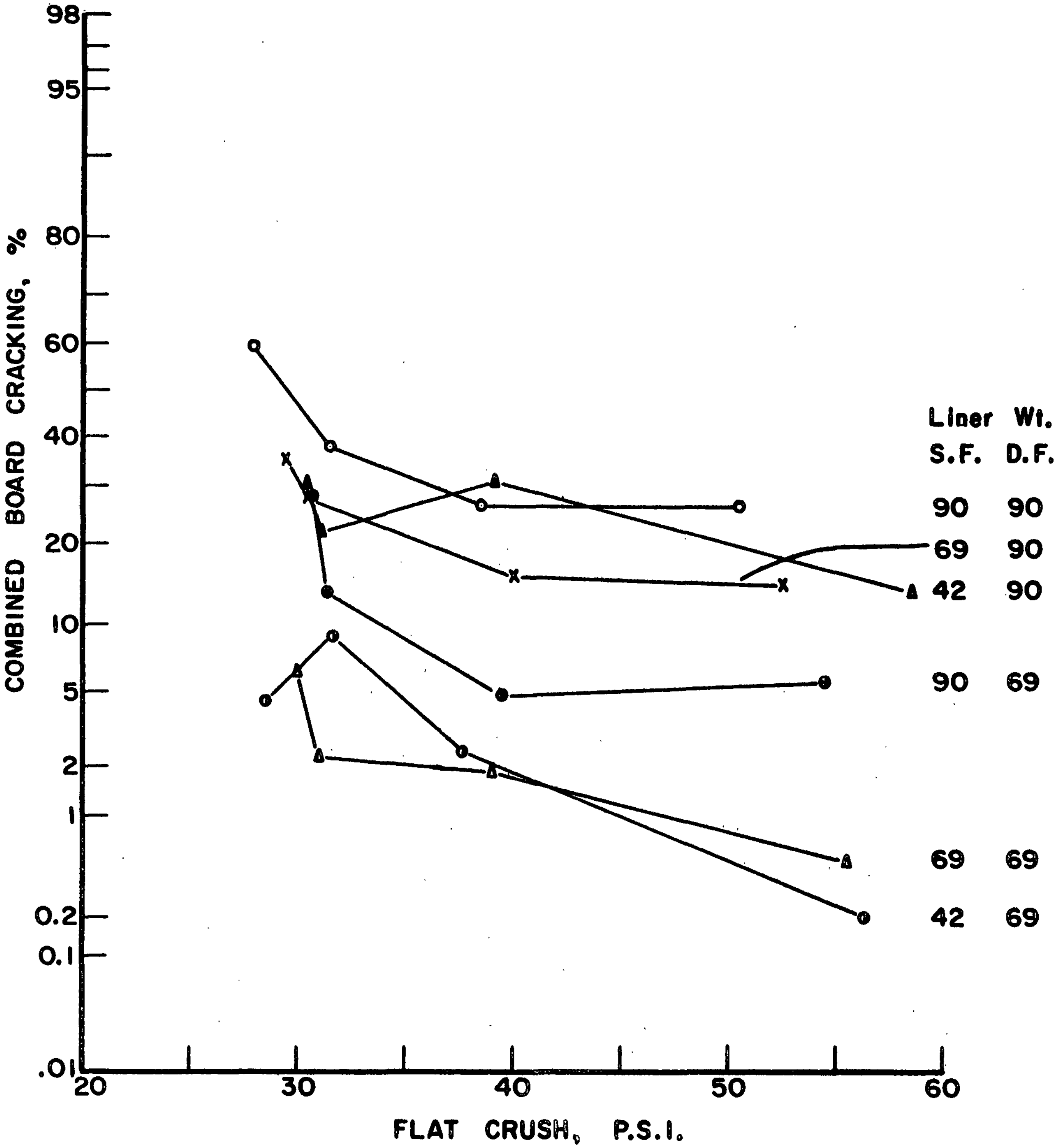


Figure 12. Effect of Medium Stiffness on Combined Board Cracking at 10% R.H.

The effect of medium flat crush on combined board cracking is illustrated in Fig. 12. Rather unexpectedly, it was found that more cracking seemed to be obtained with the lower flat crush mediums. In general, it was thought that the higher flat crush mediums would resist crushing in the final stages of folding to a greater extent — thus imposing higher lateral forces on the double-face liner and inducing higher longitudinal tensions. However, the data fail to support this viewpoint and should, therefore, be viewed with caution.

LINERBOARD CRACKING TESTER OPERATIONAL VARIABLES

As mentioned previously, it was found desirable to spray a flat black coating (Rust-Oleum No. 412) on the surface of the linerboard test specimen to assist the operator in detecting cracking. Limited trials indicated that the amount of coating was not critical — see Report 5 — and it was felt that the nonpolar vehicles in the paint would have little or no effect on the properties of the board.

However, later trials suggested that the paint coating might modify the properties of the linerboard surface. Efforts were then made to explore the possible use of various inks and dry carbon black. However, most of the inks examined were more glossy than Rust-Oleum No. 412 and the gloss made it more difficult to detect cracking for the viewing conditions used. One of the better inks in terms of lack of gloss was IPI Rotocel Black F51-538. Comparisons of linerboard cracking test results suggested, however, that there was little or no advantage to the use of the ink. Correlations with combined board cracking were also less favorable when dry carbon black was brushed on the test surface.

In conclusion, it appeared that the Rust-Oleum No. 412 spray paint gave more reproducible results than the other coatings investigated.

Limited efforts were also made to eliminate the subjective determination by the operator of the angle required to cause cracking. An optical system for detecting cracking failed to have sufficient sensitivity. Efforts were then made to obtain torque vs. angle of fold curves in the thought it would show an inflection point when cracking occurred. However, the friction in the tester could not be reduced sufficiently to obtain useful curves.

These and other variables associated with the design, manufacture, and operation of the tester could be studied further in order to

(a) improve reproducibility within or between testers,

(b) refine the test procedures, and

(c) improve correlations with combined board cracking.

From this viewpoint, the tester should be regarded as being in a developmental stage. While care is taken in the manufacture of the testers to obtain satisfactory clamping, anvil alignment, etc., differences between testers may occur which can be difficult to erase due, in part, to the subjective nature of the test. Also, users of the instrument will, no doubt, adopt procedures which are most suitable for their operations. Whether additional work on instrument variables is desirable will certainly depend on the experiences of the users.

EFFECT OF BOARD MANUFACTURING VARIABLES IN LINERBOARD CRACKING

The tendency for linerboard to crack under given folding conditions should depend on such properties as the following: (1) tensile load-elongation characteristics – particularly in the outer plies of the board which are under high tension strains during folding, (2) maximum shear strain, and (3) caliper. These properties in turn will depend on manufacturing variables such as fiber furnish, degree of delignification, refining, additives, forming, pressing, etc. Both primary and secondary stock systems should be considered.

The effects of various board manufacturing variables on conventional board properties such as bursting strength, tearing strength, etc., is generally known. However, there is little information indicating how linerboard cracking depends on board manufacturing variables. With such information, it might be possible to lessen or minimize linerboard cracking problems.

For a number of reasons, the use of handsheets to study the phenomena involved in linerboard cracking has limitations. The problems involved in duplicating the directionality effects of machine-made sheets, suggested that experimental laboratory machine trials should be a better approach.

In view of the above, it was hoped to use the Institute's web former to study the effects of selected board manufacturing variables on linerboard cracking and other board properties. However, at the time it was found impractical to produce the heavyweight sheets needed to study linerboard cracking on the web former.

As a result only a limited amount of information was gathered in this area.

In one phase of the work (see Report 7) a number of samples of 90-lb. laminated boards made with low (25%) and high (60%) hardwood contents in the furnish of the top sheet were forwarded to the Institute by the Union Camp Corporation. The boards were evaluated on the linerboard cracking tester. The results indicated that considerably greater cracking would be expected from the boards made with high hardwood contents in the top furnish.

In a number of phases of the work (see Reports 2, 3, 4, and 9) it was shown that overdrying of board may lead to substantial increases in cracking. Size press applications of starch to a commercial board resulted in increased bonding strength and other properties; however, it appeared that greater score-line cracking would be expected.

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THE INSTITUTE OF PAPER CHEMISTRY

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APPENDIX

COMPILATION OF PRELIMINARY REPORTS

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

INVESTIGATION OF A DEVICE FOR EVALUATING THE CRACKING OF LINERBOARD

Project 1108-29

Report One

A Preliminary Report

to

TECHNICAL COMMITTEE OF THE
FOURDRINIER KRAFT BOARD INSTITUTE, INC.

June 18, 1963

TABLE OF CONTENTS

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

INVESTIGATION OF A DEVICE FOR EVALUATING THE CRACKING OF LINERBOARD

INTRODUCTION

A recurrent problem in the manufacture and use of corrugated boxes is rupture or "cracking" of the double-face liner along the score when the board is folded. It is usually a seasonal problem with most difficulties being encountered during winter when inside humidities drop to low levels. Cracking is usually most severe for vertical scorelines where the score is oriented at 90° to the machine direction of the liner—because the strains set up during folding coincide with direction of least stretch. With such considerations in mind, the Institute was requested to undertake an investigation into (a) the nature and magnitude of the strains imposed in the double-face liner when folded, and (b) to evaluate methods for determining the "cracking" potential of linerboard.

As one phase, a study of the relationship of various physical characteristics of the liner to its cracking performance in the form of combined board was initiated. Particular attention has been focussed on a "foldability" tester designed at the Institute. The preliminary results are summarized herein.

MATERIALS

Twenty-three samples of linerboard were selected for the study as shown below:

Nominal Weight, lb./M ft.^{2}	No. of Samples
42	6
69	8
90	9

DOUBLE-FACING

Double-faced board was produced by hand gluing sheets of the linerboard to a "standard" single-faced board corrugated on the Institute's experimental corrugator. The single-faced board was made with a 42-lb. single-face liner and 26-lb. corrugating medium. The double-facing conditions are noted below:

1. Adhesive: silicate of soda
2. Glue roll clearance in roll coater: approximately 0.008 inch
3. Time under pressure: three minutes at 2 p.s.i. After removal from the press, the board was heated for ten minutes in a 100 to 105°C. oven.
4. Conditioning: after removal from the oven, the combined board was conditioned for at least 48 hours at 50% R.H. prior to scoring.

SCORING

The following conditions were used in scoring the combined board:

1. Score type: "V" male *vs.* flat female
2. Clearance: sum of liner and medium calipers plus 0.005 inch
3. Scoring dimensions: three 11-inch long scores were inserted in each 18-inch long sheet. The outer scores were three inches from the ends of the sheet, the third score was located in the middle of the sheet.
4. Scoring equipment: Langston slitter-scorer. A special guide was made to assist in keeping the scores parallel to the flutes.

FOLDING

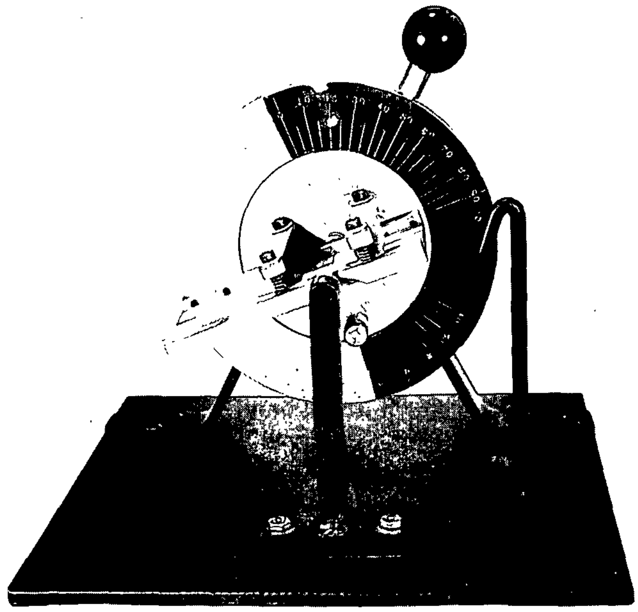
After scoring, the sheets were conditioned for at least 24 hours in the test atmosphere and folded. The folded board was taped together to standardize the handling and viewing conditions and the degree of cracking was evaluated by measuring the extent of the ruptures.

In one phase, a spray coating of flat black paint was applied to the score area by holding the container about 12 to 15 inches from the corrugated board. The purpose of the coating was to increase crack visibility and facilitate measurement of the cracking.

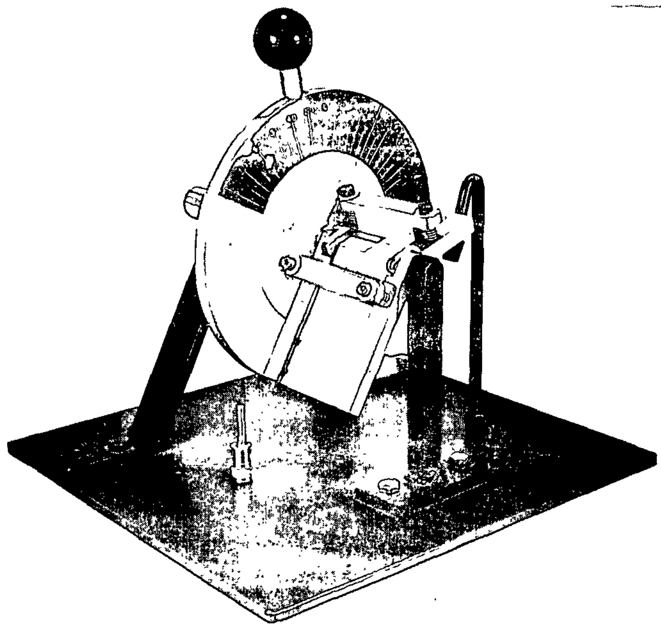
LINERBOARD EVALUATION

Each sample of linerboard was evaluated for weight, caliper, stretch and tensile. In addition, a special device was constructed to evaluate the cracking potential of linerboard. It is shown in Fig. 1. Essentially, the apparatus permits bending a specimen about a solid anvil. When the rupture occurs, a reading of the angle is obtained. It is in an early stage of development and various changes may be made to improve its correlation with combined board cracking and/or simplify its operation.

As used herein, five tests were made on each sample at each of two humidities—20 and 50% R.H.



Movable Specimen Holder Locked in Initial Clamping Position



Specimen Clamp Rotated During Test

Figure 1. Linerboard Cracking Tester

DISCUSSION OF RESULTS

The initial results obtained are tabulated in Table I. As may be noted, combined board fold evaluations were carried out at 0, 10, 20, 30, 40, and 50% R.H. In general, the degree of cracking decreased with increasing relative humidity and decreasing board weight as expected. While a number of reversals occurred it is believed these should be attributed to the subjective nature of the evaluation. This is particularly true when the cracking is not severe.

Correlations between the degree of combined board cracking and the various linerboard characteristics are tabulated in Table II. As may be noted, the correlations were carried out separately for each grade weight as well as on the combined data. In the case of the within grade correlations, the severely limited number of samples should be kept in mind. While the statistical significance of the coefficients has been indicated in the table one additional criterion should be kept in mind, i.e., the sign of the relationship. For example, it is expected that the degree of combined board cracking should decrease as the linerboard cracking angle increases—a negative relationship. Thus, positive correlation coefficients for the linerboard cracking angle test should be treated with reserve. On similar grounds, negative coefficients might be expected with stretch and positive coefficients with caliper.

With the above in mind, it may be noted

1. For the 90 pound samples, the liner cracking tester tended to be significantly related to combined board cracking—although the presence of two samples exhibiting little or no cracking presumably helped to make the coefficient significant.

TABLE I

RELATIONSHIP BETWEEN COMBINED BOARD CRACKING, RELATIVE HUMIDITY
AND LINERBOARD PROPERTIES
(Uncoated samples)

Sample No.	Combined Board Degree of Cracking, % Relative Humidity, % 0[c]	10	20	30	40	50	Liner Cracking Angle, ° Relative Humidity 20%	50%	Basis Weight, lb./M sq.ft.	Caliper, pt.	Tensile, lb./in. In	Cross	Stretch, % In	Cross
	90-lb. Double Face Liners													
2414	100.0	90.1	81.3	86.8	11.5	21.1	62.2	86.0	88.4	25.4	131.2	71.4	1.3	2.6
2420	83.5	40.2	72.0	7.4	1.8	10.0	71.0	113.8	93.5	25.4	145.4	74.1	1.4	3.6
2427	60.6	45.1	47.4	25.3	0.3	1.8	66.0	110.2	92.2	23.5	136.8	74.5	1.8	3.0
2451	28.3	11.3	8.1	34.7	2.8	4.3	64.0	123.0	87.9	26.1	105.4	62.6	1.3	2.8
2464	--[a]	95.0	66.3	5.8	6.6	0.0	85.4	107.4	84.0	24.6	167.4	78.0	2.0	5.1
2465	92.7	75.7	65.7	8.0	2.5	23.2	64.6	111.4	93.6	27.6	149.4	68.6	1.5	3.0
2466	0.0	--[a]	0.0	0.0	--[a]	--[a]	92.0	141.2	90.1	26.7	131.2	87.8	2.0	4.1
2486	0.4	--[a]	0.0	0.0	--[a]	--[a]	110.8	145.0+[b]	93.8	26.2	146.3	87.2	2.0	4.0
2491	53.3	26.5	38.0	5.8	0.3	0.9	75.4	125.2	91.6	25.6	127.6	65.3	1.6	3.0
	69-lb. Double Face Liners													
2413	54.5	27.5	3.4	1.0	0.8	2.7	90.4	123.8	70.4	20.0	114.2	55.3	1.5	3.5
2419	44.2	37.8	5.3	3.0	1.8	4.2	84.0	119.8	69.3	20.0	130.6	55.6	1.8	4.8
2422	88.1	61.7	38.2	16.8	3.4	2.0	90.2	132.0	69.4	19.6	113.1	55.6	1.3	2.0
2426	47.3	23.5	3.5	1.4	0.7	0.0	105.1	120.2	72.4	19.9	126.4	62.2	1.9	3.3
2446	77.0	74.8	22.5	12.9	6.3	15.0	97.2	125.6	73.7	20.2	116.2	60.9	1.7	3.3
2459	84.7	29.8	17.7	15.5	1.8	3.1	88.2	129.0	69.5	21.8	118.0	55.2	1.8	3.8
2463	57.8	12.2	1.6	--[a]	1.0	--[a]	82.2	125.8	69.6	22.5	124.7	58.6	1.8	4.3
2489	89.7	60.4	68.5	5.9	1.0	5.0	86.2	126.8	73.0	20.9	130.0	59.0	1.6	3.0
	42-lb. Double Face Liners													
2410	71.2	5.8	0.5	1.4	0.2	0.3	101.8	127.2	42.8	13.4	79.9	34.3	1.6	4.3
2418	29.0	4.0	0.5	0.0	0.0	0.0	103.4	122.6	44.9	12.0	95.5	36.8	1.6	3.9
2421	49.7	19.0	0.7	3.0	0.4	0.4	94.0	123.6	42.7	12.6	86.7	37.2	1.8	3.8
2424	8.7	1.1	0.0	0.9	0.3	--[a]	97.8	128.6	44.0	10.4	84.2	42.2	2.0	4.6
2436	47.9	14.5	1.4	1.4	0.2	0.0	96.0	126.4	43.0	12.1	88.6	37.0	2.1	3.7
2476	28.8	5.3	0.1	0.5	0.0	0.0	96.0	131.2	42.8	12.8	85.9	41.4	1.8	3.0

[a]Specimens not evaluated in view of results obtained at other conditions.

[b]One or more specimens did not crack at maximum angle permitted by tester.

[c]Corresponds to 16 hours oven drying.

Note: Weight, caliper, tensile and stretch were determined at 50% R.H.

TABLE II

CORRELATION OF LINERBOARD PROPERTIES WITH COMBINED BOARD CRACKING
(Uncoated samples)

Test	Correlation Coefficient Combined Board Cracking 0% R.H.	10% R.H.	20% R.H.	30% R.H.	40% R.H.	50% R.H.	0+10% (Composite)	0+10+20% (Composite)
	90-lb. Liner Samples (N=9)							
Liner cracking angle—20% R.H.	-0.63	-0.48	-0.60	-0.57	-0.38	-0.60	-0.57	-0.58
" " " —50% R.H.	-0.90[a]	-0.88[a]	-0.89[a]	-0.73[b]	-0.81[a]	-0.65	-0.90[a]	-0.91[a]
Caliper	-0.27	-0.25	-0.30	-0.22	-0.15	0.38	-0.27	-0.27
Tensile, in	0.44	0.53	0.45	-0.38	0.12	0.04	0.49	0.48
Stretch, in	-0.42	-0.23	-0.42	-0.61	-0.39	-0.67[b]	-0.33	-0.37
	69-lb. Liner Samples (N=8)							
Liner cracking angle—20% R.H.	-0.14	0.15	-0.15	0.07	0.24	0.18	0.02	-0.05
" " " —50% R.H.	0.88[a]	0.39	0.55	0.76[b]	0.31	0.05	0.68	0.65
Caliper	0.15	-0.46	-0.07	-0.11	-0.28	-0.21	-0.20	-0.16
Tensile, in	-0.36	-0.23	0.09	-0.57	-0.47	-0.21	-0.33	-0.17
Stretch, in	-0.51	-0.50	-0.48	-0.41	-0.23	-0.05	-0.56	-0.55
	42-lb. Liner Samples (N=6)							
Liner cracking angle—20% R.H.	0.09	-0.63	-0.19	-0.62	-0.50	-0.17	-0.10	-0.10
" " " —50% R.H.	-0.24	-0.42	-0.45	-0.26	-0.20	-0.35	-0.31	-0.32
Caliper	0.83[b]	0.36	0.25	0.25	-0.22	0.54	0.79	0.79
Tensile, in	-0.37	0.06	0.25	-0.38	-0.44	-0.44	-0.29	-0.28
Stretch, in	-0.35	0.25	0.33	0.19	0.38	-0.38	-0.23	-0.22
	Combined Data (N=23)							
Liner cracking angle—20% R.H.	-0.46[b]	-0.49[b]	-0.67[a]	-0.61[a]	-0.42[b]	-0.57[a]	-0.50[b]	-0.58[a]
" " " —50% R.H.	-0.63[a]	-0.68[a]	-0.68[a]	-0.69[a]	-0.70[a]	-0.60[a]	-0.68[a]	-0.71[a]
Caliper	0.25	0.42[b]	0.54[a]	0.35	0.36	0.42[b]	0.35	0.43[b]
Tensile, in	0.36	0.58[a]	0.64[a]	0.16	0.36	0.35	0.49[b]	0.56[a]
Stretch, in	-0.47[b]	-0.35	-0.46[b]	-0.53[a]	-0.39	-0.53[a]	-0.43[b]	-0.46[b]

[a]Significant at 01 level.

[b]Significant at 05 level.

2. In the other grade weights, none of the linerboard tests appeared to be significantly related to combined board cracking although the limited number of samples in each group and resulting property range should be kept in mind.
3. For the combined data, the liner cracking angle appeared to be best related to combined board cracking.

In general, the above results suggested that the new test might have promise; however, it was not clear whether the relatively poor relationships should be attributed to (a) variability in the subjective evaluations of the cracking in the combined board and linerboard tests, or (b) whether design changes were needed in the linerboard tester itself. To investigate the first alternative, it was proposed to repeat the work applying a black paint coating to the scored areas of the combined board and to the test areas of the linerboard cracking angle specimens. The purpose of the coating was to provide a black background against which cracks would be more visible, thus improving the measurements.

The results obtained on the coated samples are summarized in Table III and the linear correlation coefficients are shown in Table IV in the first four columns. The last column in Table IV gives the correlation between the logarithm of the combined board cracking at 20% R.H. and the various test properties. In the table it may be noted that the linear correlations are similar in many respects to those obtained with the uncoated samples. Improvements in correlation seemed to be obtained with the 0% R.H. combined board samples with 90-pound liners; however, this may be due, in part, to the presence of the two low cracking samples (2466 and 2486) in this group. To illustrate

TABLE III

COMPARISON OF COMBINED BOARD AND LINER CRACKING RESULTS
(Black coated fold area)

Sample No.	Combined Board Cracking, % Relative Humidity, % 0	20	30	50	Liner Cracking Angle, ° Relative Humidity, % 20[a]	50[a]
			90-lb. Liners			
2414	100.0	92.1	87.4	47.5	51.6(35.2)	66.8(45.6)
2420	99.6	40.8	40.7	6.4	51.8(36.2)	74.2(52.4)
2427	96.9	22.6	17.8	1.9	62.4(45.4)	78.0(58.0)
2451	92.7	9.9	5.3	0.8	64.4(46.4)	73.2(53.8)
2464	100.0	94.3	83.9	35.8	56.0(38.4)	72.4(51.4)
2465	100.0	59.6	55.8	24.4	52.6(38.6)	73.2(50.0)
2466	42.1	0.1	0.0	0.0	86.4(67.6)	131.6(109.6)[b]
2486	33.8	0.0	0.0	0.0	97.4(77.8)	135.0(120.4)[b]
2491	95.5	25.1	12.8	4.8	64.8(45.4)	84.4(61.0)
			69-lb. Liners			
2413	91.3	25.7	3.6	1.4	72.0(46.0)	77.8(55.2)
2419	80.0	25.5	2.2	0.7	64.0(45.6)	72.8(52.4)
2422	94.3	61.7	13.2	5.6	66.0(45.8)	73.6(53.0)
2426	95.4	15.6	2.4	0.0	62.0(46.4)	68.2(52.8)
2446	95.6	67.2	15.6	13.0	63.0(43.4)	82.2(58.2)
2459	94.9	65.7	5.1	1.8	67.8(46.4)	81.8(57.6)
2463	98.9	46.4	3.3	3.2	59.4(42.4)	77.0(54.4)
2489	98.0	79.6	21.4	14.9	59.2(39.4)	85.4(62.0)
			42-lb. Liners			
2410	73.2	16.2	1.4	0.1	69.6(50.6)	82.4(69.0)
2418	68.2	1.8	0.7	0.1	74.8(54.0)	79.6(64.4)
2421	62.0	9.4	1.2	0.8	72.0(50.0)	86.6(63.2)
2424	75.6	13.0	1.0	0.2	80.2(56.6)	94.8(77.6)
2436	86.0	27.1	3.1	1.6	75.0(52.8)	80.6(62.6)
2476	80.9	4.4	1.5	0.1	78.6(51.4)	86.2(65.0)

[a]The first figure is the angle at which an open crack was observed. The figure in parentheses is the angle at which the first minor crack in the coating was observed.

[b]One or more specimens did not crack at the maximum angle permitted by the tester.

TABLE IV

CORRELATION OF LINER PROPERTIES WITH COMBINED BOARD CRACKING
(Black coated samples)

Test	Correlation Coefficient Combined Board Cracking 0% R.H.	20% R.H.	30% R.H.	50% R.H.	Logarithm (20% R.H.)
		90-lb. Liner Samples (N=9)			
Liner cracking angle—20% R.H.					
First coating crack (FCC)	-0.97[a]	-0.74[b]	-0.72[b]	-0.60	-0.97[a]
Open crack (OC)	-0.96[a]	-0.74[b]	-0.73[b]	-0.60	-0.97[a]
Liner cracking angle—50% R.H.					
First coating crack (FCC)	-0.99[a]	-0.68[b]	-0.65	-0.54	-0.98[a]
Open crack (OC)	-0.99[a]	-0.68[b]	-0.65	-0.54	-0.97[a]
Caliper	-0.36	-0.20	-0.17	-0.06	-0.35
Tensile, in	0.03	0.51	0.53	0.40	0.17
Stretch, in	-0.63	-0.25	-0.25	-0.24	-0.58
		69-lb. Liner Samples (N=8)			
Liner cracking angle—20% R.H.					
FCC	-0.45	-0.59	-0.69	-0.80[b]	-0.56
OC	-0.35	-0.25	-0.34	-0.44	-0.19
Liner cracking angle—50% R.H.					
FCC	0.48	0.77[b]	0.74[b]	0.80[b]	0.69
OC	0.38	0.81[b]	0.65	0.72[b]	0.81[b]
Caliper	0.45	0.33	-0.12	0.00	0.38
Tensile, in	-0.22	-0.18	-0.06	0.02	-0.25
Stretch, in	-0.07	-0.34	-0.48	-0.30	-0.38
		42-lb. Liner Samples (N=6)			
Liner cracking angle—20% R.H.					
FCC	0.24	0.00	-0.18	-0.14	-0.08
OC	0.44	-0.19	-0.06	-0.14	-0.19
Liner cracking angle—50% R.H.					
FCC	0.04	0.02	-0.39	-0.46	0.20
OC	-0.06	-0.10	-0.33	-0.27	0.19
Caliper	-0.10	-0.04	0.15	-0.03	-0.03
Tensile, in	-0.15	-0.36	-0.09	0.15	-0.64
Stretch, in	0.59	0.64	0.65	0.69	0.61
		Combined Data (N=23)			
Liner cracking angle—20% R.H.					
FCC	-0.92[a]	-0.70[a]	-0.59[a]	-0.55[a]	-0.91[a]
OC	-0.88[a]	-0.70[a]	-0.65[a]	-0.59[a]	-0.84[a]
Liner cracking angle—50% R.H.					
FCC	-0.90[a]	-0.53[a]	-0.41	-0.37	-0.89[a]
OC	-0.86[a]	-0.46[b]	-0.38	-0.34	-0.85[a]
Caliper	0.20	0.35	0.47[b]	0.40	0.01
Tensile, in	0.23	0.48[b]	0.61[a]	0.51[b]	0.10
Stretch, in	-0.45[b]	-0.29	-0.30	-0.28	-0.39

[a]Significant at 01 level. [b]Significant at 05 level.

the above, the 0 and 20% R.H. combined board cracking results are plotted against the liner cracking angle in Fig. 2. It is apparent that the regression line will be quite dependent upon the position of the two isolated points at the right for the 0% combined board results. The 20% R.H. combined board results plotted on the right suggest that a nonlinear relationship would give a better fit to the 20% R.H. combined board data than the straight line shown in the figure. For example, in Table IV fitting an exponential function to the data raised the correlations considerably.

In any event, nonlinear correlations of the data may be helpful and this avenue will be explored as time permits.

In general, it appears that the linerboard cracking device may have promise for mill quality evaluation; however, further improvements in design appear necessary to improve its correlation with field performance.

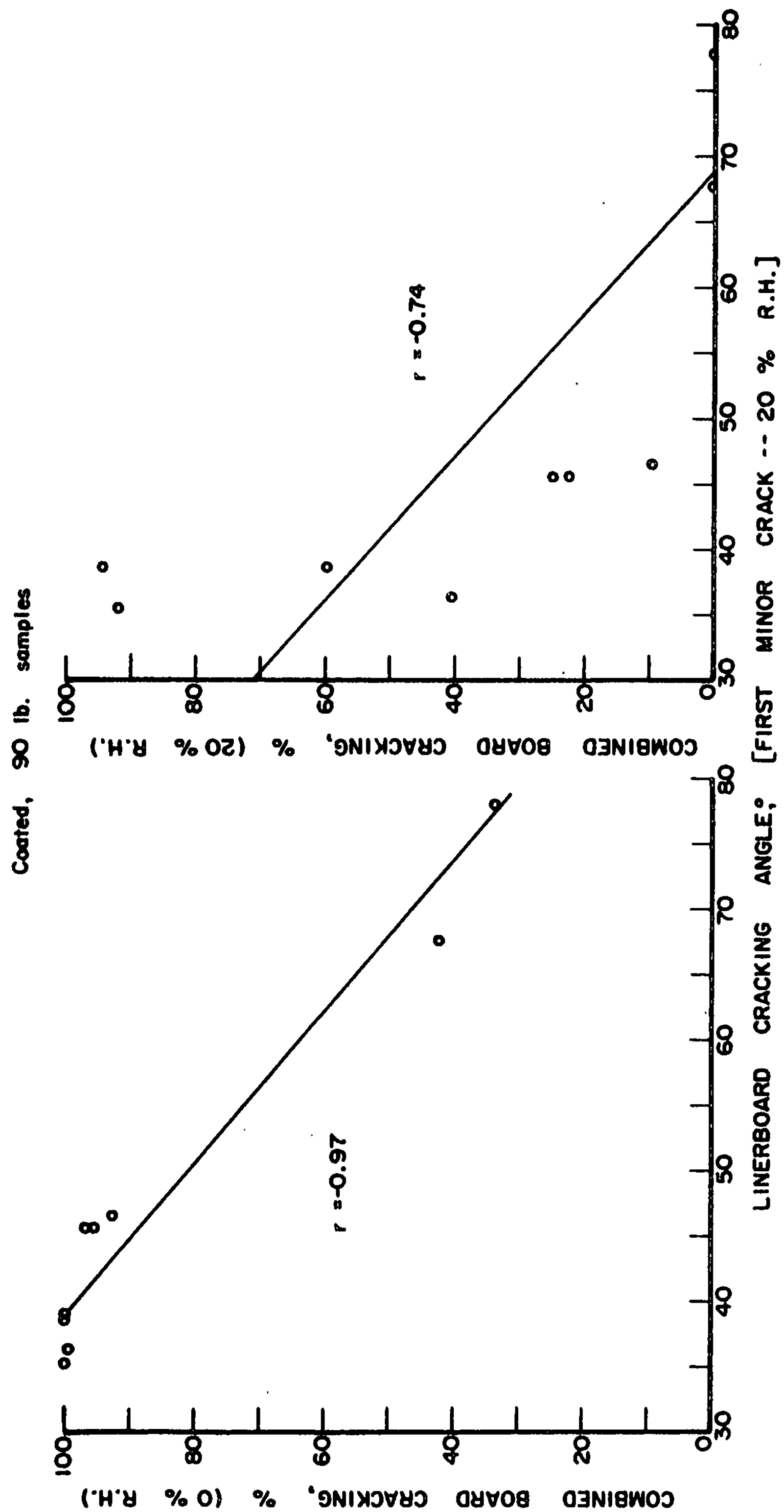


Figure 2. Relationship Between Combined Board Cracking and Liner Cracking Angle

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

INVESTIGATION OF AN IMPROVED DEVICE FOR EVALUATING THE CRACKING POTENTIAL OF LINERBOARD

Project 1108-29

Report Two

A Preliminary Report

to

TECHNICAL COMMITTEE
FOURDRINIER KRAFT BOARD INSTITUTE, INC.

September 12, 1963

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

INVESTIGATION OF AN IMPROVED DEVICE FOR EVALUATING THE CRACKING POTENTIAL OF LINERBOARD

SUMMARY

A recurrent problem in the manufacture and use of corrugated boxes is rupture or cracking of the double-face liner along the score when the board is folded. Cracking is usually most severe for vertical scorelines when the score is oriented at 90° to the machine direction of the liner—because the strains set up during folding coincide with the direction of least stretch. With such considerations in mind, the Institute was requested to undertake an investigation to evaluate methods for determining the cracking potential of linerboard.

The initial results obtained in this study were described in Report One dated June 18, 1963. In this particular report attention was focused on a "foldability" tester designed at the Institute for determining the cracking potential of linerboard. This tester was used for an initial study of the relationship of various physical characteristics of the liner to its cracking performance in the form of combined board. The initial results indicated that the new tester exhibited some promise; however, additional refinements appeared desirable to permit better evaluations within individual grades of linerboard.

The results in the present study were obtained using the modified tester. The principal change made was to redesign the anvil heads over which the specimen is bent to prevent cutting of the underside of the specimen. The anvil heads were machined to have 0.010 inch radii for this study. Other changes in the tester are described in the text.

To test the efficiency of the device for predicting combined board cracking, the 90-lb. liner samples used in the previous study were used as double-face liners and laminated to single-faced board having a 90-lb. liner. The range of cracking was increased by subjecting the linerboards before fabrication to heat or humidity to change their characteristics. After scoring and folding, the degree of cracking of the combined boards and the liner cracking angle were determined at 10, 20, 30, 40, and 50% R.H.

In general, the results of this study indicated that:

1. The linerboard cracking device appears to be a practical means for evaluating the cracking potential of linerboard because it appears to be significantly related to combined board cracking. Recommendations with regard to possible additional improvements are mentioned in the text.

2. The relationship between combined board cracking and relative humidity was such that a probability-type equation appeared to fit the data reasonably well.

3. Exponential or probability-type equations appeared to best fit the liner cracking *vs*. combined board cracking data although the latter may be preferred at this time.

LINERBOARD FOLDABILITY TEST

Ten specimens of each linerboard sample were evaluated at each humidity level with the fold line at right angles to the machine direction. As in the case of the combined board samples, a spray coating of flat black paint was used to increase crack visibility. The rupture angle associated with the first appearances of a crack in the liner surface was measured. Efforts were also made to measure the angle associated with a more severe degree of cracking; however, these readings would have been in excess of the maximum angle permitted by the tester in the higher humidities. Therefore, the severe cracking criterion was discontinued; however, it may be tried in future work in an effort to improve and simplify the routine evaluation of linerboard.

FOLDING

As in the previous work, five sheets of board with 3-11 inch long panel scores per sheet were evaluated for cracking for each sample in each atmosphere. Thus, each percentage cracking value is based on an examination of 165 inches of scoreline. The folded board was taped together to standardize the viewing and handling conditions and the cumulative length of severe cracks was measured—a minimum length of 0.10 inch was used corresponding to a minimum percentage cracking of about 0.1%.

To increase crack visibility, a spray coating of flat black paint was used as described in the previous study. The length and occurrence of severe cracks was judged in comparison with a reference scoreline.

DOUBLE-FACING AND SCORING

Double-faced board was made by hand gluing sheets of the linerboard to a single-faced board corrugated on the Institute's experimental corrugator. With the exception that a 90-lb. liner was used as the single-face liner, the same conditions were used as specified in Report One.

1. At least 72 hours exposure to 90% R.H. and 73°F. followed by preconditioning at less than 35% R.H. and conditioning at 50% and 73°F. prior to fabrication or evaluation—Sample numbers 2414, 2420, 2427, 2464, 2465, and 2491.

2. At least 36 hours exposure at 125°C. followed by preconditioning and conditioning as noted in (1) above—Sample numbers 2427, 2451, 2466, 2486, and 2491.

MATERIALS

The physical characteristics of the 90-lb. liner samples used are tabulated in Table I.

TABLE I

PHYSICAL CHARACTERISTICS OF 90-LB. LINER SAMPLES

Sample No.	Basis Weight, lb./M ft.^{2}	Caliper, pt.	Tensile, lb./in. In	Tensile, lb./in. Cross	Stretch, % In	Stretch, % Cross	Ply Adhesion, lb./4 in.^{2}
2414	88.4	25.4	131.2	71.4	1.3	2.6	--
2420	93.5	25.4	145.4	74.1	1.4	3.6	145
2427	92.2	23.5	136.8	74.5	1.8	3.0	133
2451	87.9	26.1	105.4	62.6	1.3	2.8	112
2464[a]	84.0	24.6	167.4	78.0	2.0	5.1	182
2465	93.6	27.6	149.4	68.6	1.5	3.0	135
2466[b]	90.1	26.7	131.2	87.8	2.0	4.1	118
2486[b]	93.8	26.2	146.3	87.2	2.0	4.0	158
2491	91.6	25.6	127.6	65.3	1.6	3.0	127

[a] Laminated (2-42 lb. plies).
[b] Laminated (fourdrinier board laminated to extensible sheet).

All the above samples were fabricated into double-faced board and evaluated for cracking at 10, 20, 30, 40, and 50% R.H. In addition, portions of the following samples were treated as noted below prior to the double-facing operation.

$$P = kt\int_{\infty}^{\theta}(1/\sqrt{2\pi})\exp[-(\theta - \bar{\theta}_f)^2/2\sigma_\theta^{\ 2}]\ d\theta \qquad (6)$$

Thus, this approach suggests that for a given sample, the degree of combined board cracking will be nonlinearly dependent on the rupture angle observed in the linerboard test. A decrease in humidity, e.g., which has the effect of decreasing the rupture stretch and angle θ_f would have a marked effect on the probability or degree of combined board cracking.

Equation (6) cannot be explicitly integrated; however, tables of areas under the normal distribution curve are readily available (1). The form of Equation (6) indicates that one analytical approach which might be useful in relating combined board cracking and liner cracking angle would be the response or probit curve technique described in Reference (2). In using this approach, the percentage cracking values would be transformed to values of the normal deviate for correlation purposes.

Equation (4) is in agreement with the general observations that other things being equal (1) the thicker the sheet, the smaller should be the angle of fold required to produce fracture, and (2) the smaller the potential stretch in the outside surface layers, the smaller should be the angle of fold required to produce fracture.

The combined board evaluation differed from that used for the linerboard in that the combined board is folded 180 degrees and the extent of the cracking is observed. This would be analogous to bending the liner in the linerboard test to a given angle and observing the extent of the cracking. Thus, the percentage cracking figures are equivalent to working with cumulative probability distributions.

In general, failure will occur when the rupture stretch ($\epsilon_{\underline{f}}$) in the outer layers of the double-face liner is exceeded. Assuming that the rupture stretch in the outside layers is normally distributed about some average value $\bar{\epsilon}_{\underline{f}}$ with standard deviation σ_ϵ, then (1)

$$P = \int_{-\infty}^{\epsilon} (1/\sqrt{2\pi}) \exp[-(\epsilon - \bar{\epsilon}_{\underline{f}})^2/2\sigma_\epsilon^2] \, d\epsilon \qquad (5)$$

where $\underline{P}$ = failure probability

ϵ = strain applied in combined board fold at outer surface of double-face liner

$\bar{\epsilon}_{\underline{f}}$ = average rupture strain in outer surface of double-face liner

σ_ϵ = standard deviation of rupture strain.

Making the appropriate substitutions from Equations (2) and (3) into Equation (5) and making the further assumption that the variance in thickness is small in comparison with that of $\theta_{\underline{f}}$, Equation (5) may be written as follows:

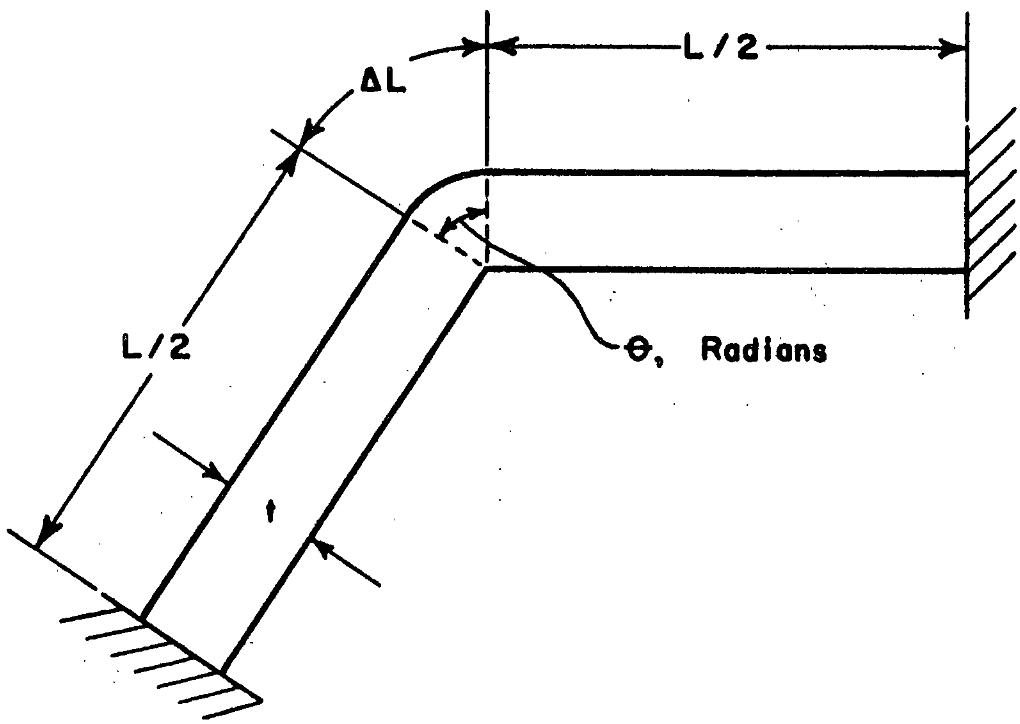

Figure 2. Idealized Representation of Strain Induced in Linerboard Foldability Test

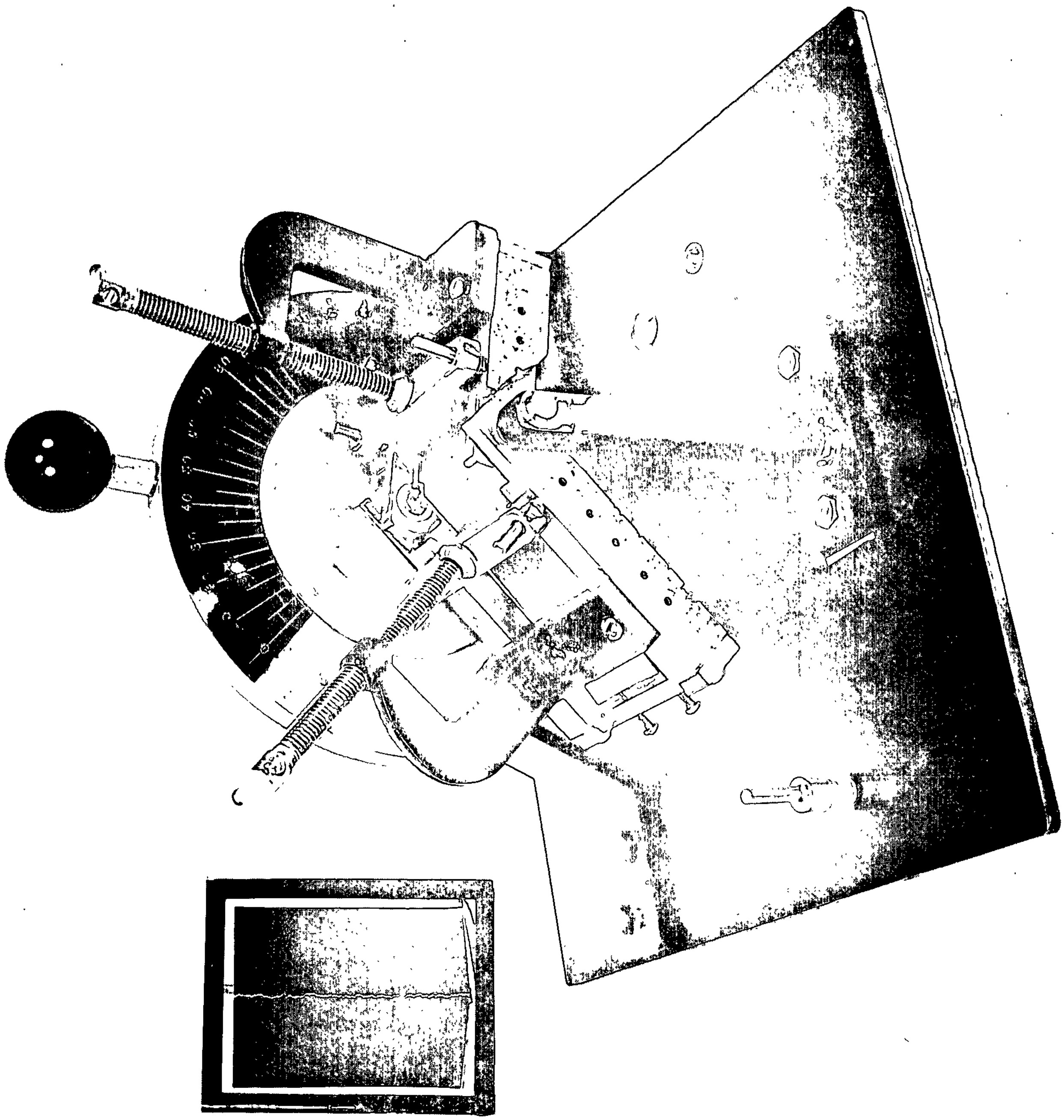

Figure 1. Modified Linerboard Foldability Tester

LINERBOARD FOLDABILITY TESTER

As illustrated in Fig. 1, the linerboard foldability apparatus involves folding a strip of linerboard about a steel anvil. The strip is clamped at the ends; therefore, the outer surface of the liner is subjected to tensile strains arising from the elongation of the neutral axis and to tensile strains arising from the flexure of the strip. The first type of strain will be proportional to the tensile stiffness of the board; the second type of strain will be proportional to the bending and shear stiffness of the board.

From a more simplified standpoint, the strains occurring in the linerboard are schematically illustrated in Fig. 2. As shown in the figure, the change in length (ΔL) of the top surface of the specimen would be as follows:

$$\Delta L = \theta t \tag{1}$$

where θ = angle of rotation, radians and t = specimen thickness.

It will be assumed that the maximum strain (ϵ) in the outer surface is concentrated in a small zone near the center of the bent area and may be represented as follows:

$$\epsilon = k\theta t \tag{2}$$

where k = constant

Then, when the maximum stretch (ϵ_f) in the outer surface is exceeded, rupture will occur, i.e.:

$$\epsilon_f = k\theta_f t \tag{3}$$

where θ_f = angle of rotation when rupture occurs,

$$\text{or } \theta_f = \epsilon_f/kt = k_1 \epsilon_f/t \tag{4}$$

this reason, it was thought desirable to concentrate attention on the 90-lb. grade and to artificially increase the number of samples in this grade by (a) subjecting portions of six samples to high humidity (90% R.H.) for at least 12 hours to relax a portion of the stresses built in during manufacture, and (b) to degrade portions of five samples by subjecting them to a temperature of 125°C. for 36 hours. After reconditioning, the humidity relaxation technique would have the tendency to reduce cracking failure under given conditions as compared to untreated samples, since the relaxed samples should have a higher stretch. The samples treated by heating, on the other hand, would be expected to crack more readily than the untreated controls. In addition, to increasing the severity of cracking, the combined board samples were all fabricated using a standard single-faced sample having a 90-lb. single-face liner rather than the 42-lb. liner sample used in the previous trials.

The results obtained are summarized herein.

INTRODUCTION

Preliminary Report One dated June 18, 1963 described initial results obtained in an investigation of methods for determining the cracking potential of linerboard. For this purpose, a study of the relationship of various physical characteristics of the liner to its cracking performance in the form of combined board was initiated. Particular attention was focused on the foldability tester designed at the Institute.

In general, the results indicated that the new tester might have promise; however, further improvements in design appeared necessary to improve its correlation with combined board cracking. Specifically, it was observed that the device tended to cut the under side of the liner - thus possibly relieving the tensile stresses causing cracking to some degree. To prevent cutting, the anvil heads were redesigned so as to have a small radius - 0.010 inch with 0.032 inch spacing between anvils for the trials reported herein. The specimen holder was also redesigned to permit substitution of anvils having other tip radii in the event that cutting still occurred with the 0.010 inch radii anvils. A change in clamping was also made to give more even clamping pressures and faster clamping action. It was thought that toggle-action clamps would be suitable; however, slippage occurred. Because of time limitations, the original clamps were then crudely modified to a centrally applied screw closure system.

In the previous work, samples of 42, 69, and 90-lb. liner samples were employed; however, only a limited number of samples were available in each grade. This, coupled with the variability involved in the combined board and linerboard evaluations, made it difficult to assess the degree of relationship between combined board cracking and linerboard evaluations within grades. For

DISCUSSION OF RESULTS

A tabulation of the combined board cracking results together with the linerboard cracking evaluations at each humidity level are summarized in Table II. As may be noted, no severe cracking was recorded for Samples 2466 and 2486 at any humidity level for the material given no special prefabrication treatment. Only slight amounts of cracking were recorded at 10 and 20% R.H. for the portions of these samples heated at 125°C. prior to fabrication. In the linerboard evaluation of these samples, no cracking was observed at the highest angle permitted by the tester. Thus, the linerboard tests were in qualitative agreement with the combined board cracking results. However, the results were not suitable for quantitative analyses and were not used in the following analyses.

Inspection of the table indicates that, in general, both the combined board and linerboard tests exhibit the expected trends with folding humidity and fabrication treatment. For example, with increasing folding humidity, the degree of combined board cracking decreases and the linerboard cracking angle increases. Similarly, the samples heated at 125°C. prior to fabrication into combined board tended to exhibit increased combined board cracking and smaller linerboard cracking angles relative to the untreated samples.

EFFECT OF HUMIDITY ON COMBINED BOARD CRACKING

To illustrate the effect of humidity at time of folding, Fig. 3 through 8 were prepared. Figures 3 and 4 show results plotted in linear and semilogarithmic coordinates, respectively; Fig. 5 through 8 show the results plotted on arithmetic probability paper. (Note: The curves were drawn in by "eye" in all figures.) Inspection of the figures indicates that:

TABLE II

COMBINED BOARD AND LINERBOARD CRACKING RESULTS

(Black coated)

Sample No.	Combined Board Cracking, %					Linerboard Cracking Angle, °[c]									
	10% R.H.	20% R.H.	30% R.H.	40% R.H.	50% R.H.	10% R.H.		20% R.H.		30% R.H.		40% R.H.		50% R.H.	
						Av.	V	Av.	V	Av.	V	Av.	V	Av.	V
2414	99.7	96.1	76.7	37.5	30.9	41.6	8.4	44.2	7.0	47.3	5.9	56.1	12.8	56.7	7.8
2420	77.4	53.5	21.2	1.7	1.0	45.4	5.7	51.6	7.3	57.6	9.4	71.2	14.6	67.2	9.3
2427	69.5	33.4	6.2	0.1	0.2	51.7	3.7	58.2	7.8	64.6	9.3	76.9	8.5	78.5	8.0
2451	31.1	17.1	1.4	0.1	0.1	51.6	5.5	59.3	8.1	71.7	8.4	76.8	6.2	76.2	5.2
2464	99.9	99.6	81.5	39.1	19.9	45.4	3.1	54.3	6.8	60.0	6.1	68.5	7.9	73.1	7.0
2465	84.4	69.7	26.1	2.7	2.2	42.9	5.2	50.2	4.6	59.2	5.6	62.6	9.1	65.2	6.1
2466	0.0	0.0	0.0	0.0	0.0	--[a]	--	--[a]	--	--[a]	--	--[a]	--	--[a]	--
2486	0.0	0.0	0.0	0.0	0.0	--[a]	--	--[a]	--	--[a]	--	--[a]	--	--[a]	--
2491	53.0	25.6	4.8	0.1	0.3	51.1	8.0	61.5	11.3	72.2	10.9	73.7	9.0	80.5	10.2
						After High Humidity Relaxation Treatment									
2414	99.9	97.3	65.3	38.1	21.8	40.8	5.8	47.8	4.8	57.2	5.6	57.5	9.4	58.9	7.4
2420	78.3	42.8	11.0	1.6	1.5	48.4	6.3	55.3	4.3	64.1	4.1	64.5	6.0	65.8	8.2
2427	49.3	28.2	3.1	0.2	0.1	54.6	5.1	59.6	4.4	72.1	6.4	68.0	10.2	75.0	4.6
2464	99.9	100.0[b]	81.0	32.2	6.4	44.2	6.9	53.7	5.8	66.7	7.7	63.6	7.0	73.8	7.7
2465	81.6	69.4	21.9	1.6	0.5	43.6	5.6	51.8	5.1	63.5	6.0	57.7	7.7	68.2	6.9
2491	47.1	35.5	5.4	0.4	0.2	52.2	7.1	58.1	8.1	72.9	7.4	74.1	3.1	75.7	9.5
						After Drying at 125°C. for 36 Hours									
2427	94.3	88.9	51.4	34.2	16.3	45.1	8.2	48.7	6.1	58.0	5.7	61.6	5.8	62.5	4.8
2451	96.0	92.9	51.9	39.1	10.0	41.1	5.7	49.2	5.6	57.9	4.6	57.1	2.7	59.0	5.9
2466	1.0	0.5	0.0	0.0	0.0	--[a]	--	--[a]	--	--[a]	--	--[a]	--	--[a]	--
2486	10.0	0.2	0.0	0.0	0.0	--[a]	--	--[a]	--	--[a]	--	--[a]	--	--[a]	--
2491	96.4	90.8	44.3	17.6	5.0	44.3	8.4	50.7	4.9	57.0	5.5	59.5	11.0	63.0	5.6

[a]In excess of maximum angle (100°) permitted by tester.

[b]Arbitrarily considered as 99.9 for transformation to the normal deviate.

[c]Linerboard cracking angle corresponding to initial observed crack.

Note: V equals coefficient of variation.

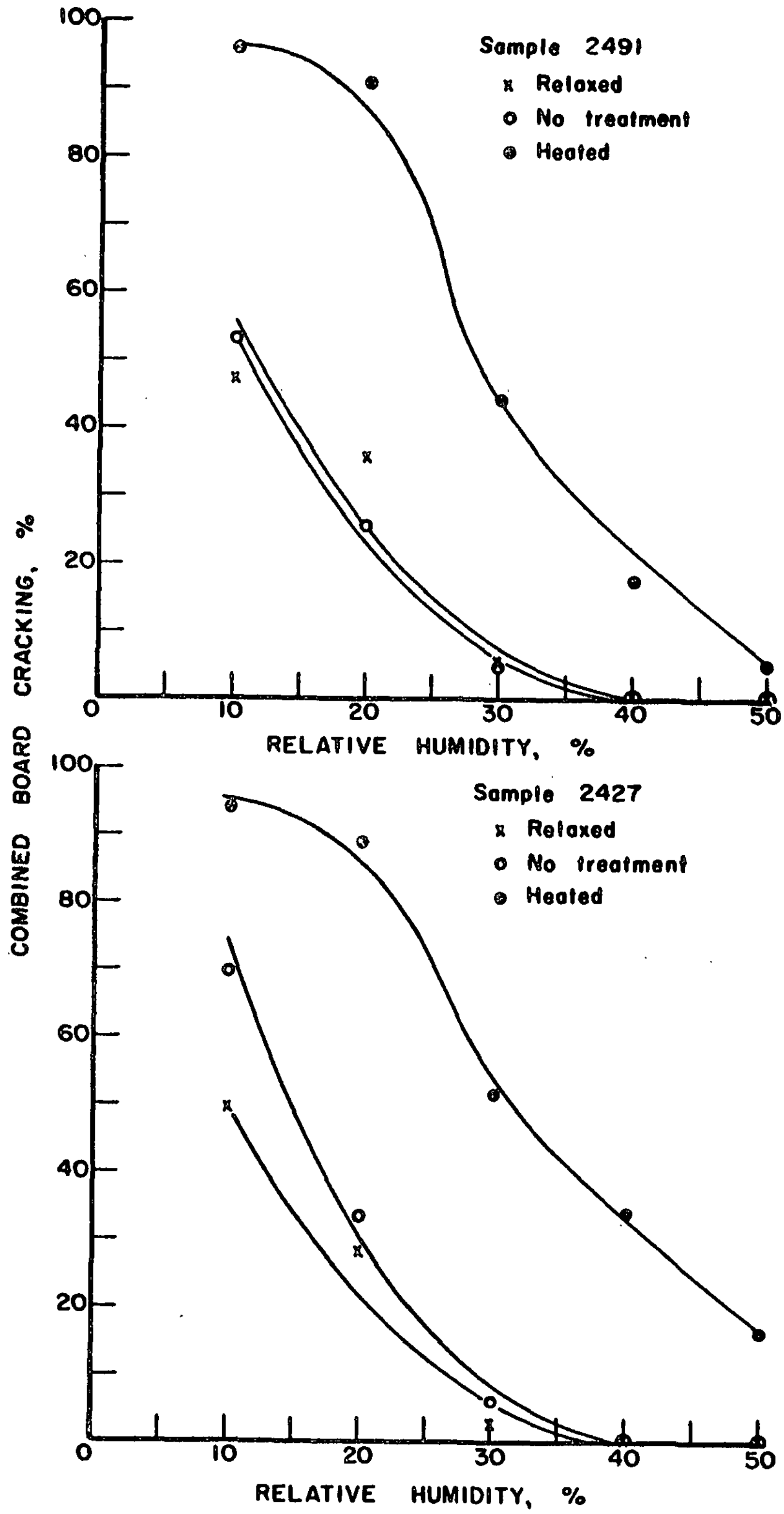

Figure 3. Effect of R.H. on Combined Board Cracking For Samples 2427 and 2491 (Linear Coordinates)

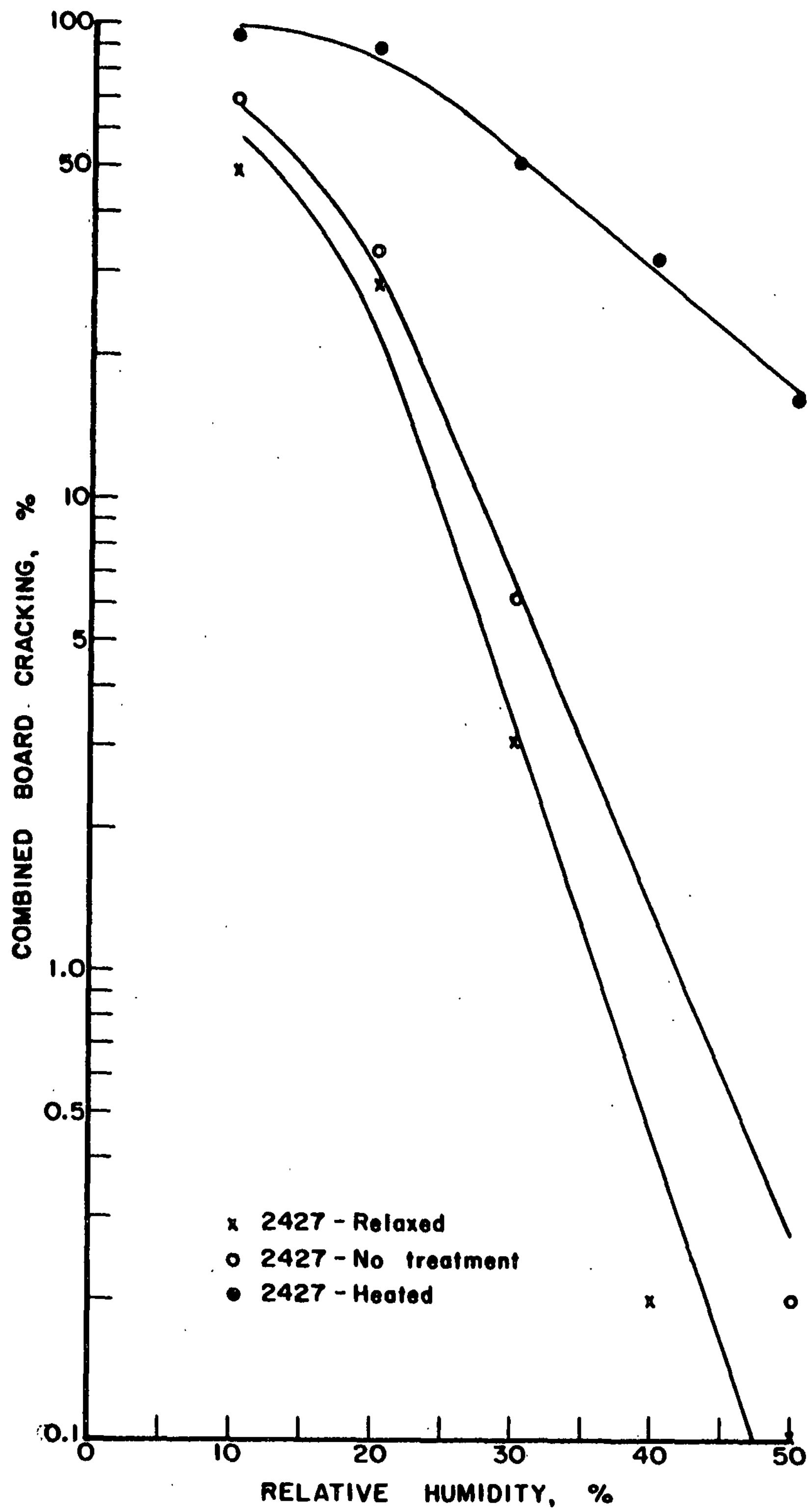

Figure 4. Effect of R.H. on Combined Board Cracking For Sample 2427 (Semilogarithmic Coordinates)

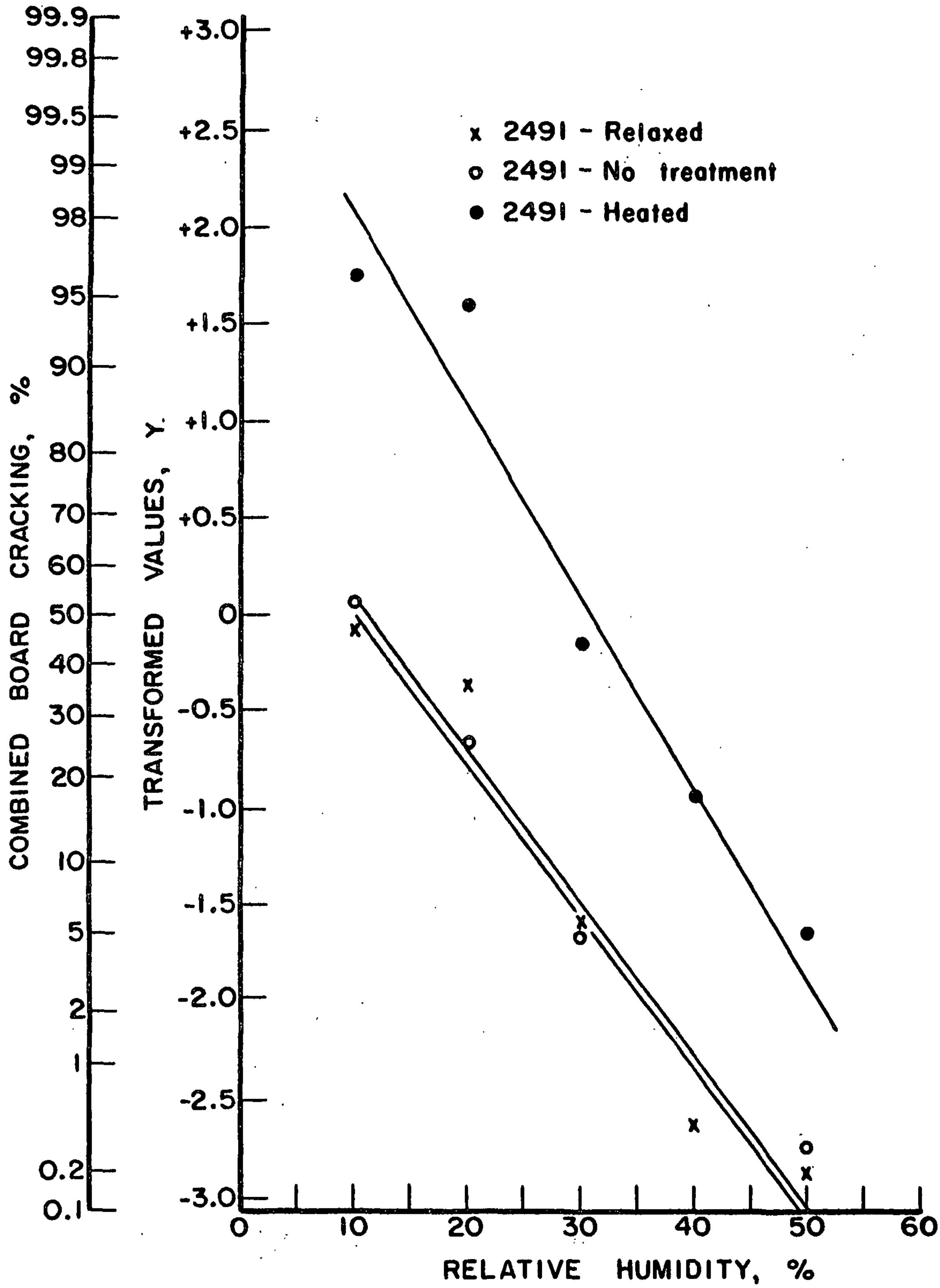

Figure 5. Effect of R.H. on Combined Board Cracking For Sample 2491
(Arithmetic Probability Coordinates)

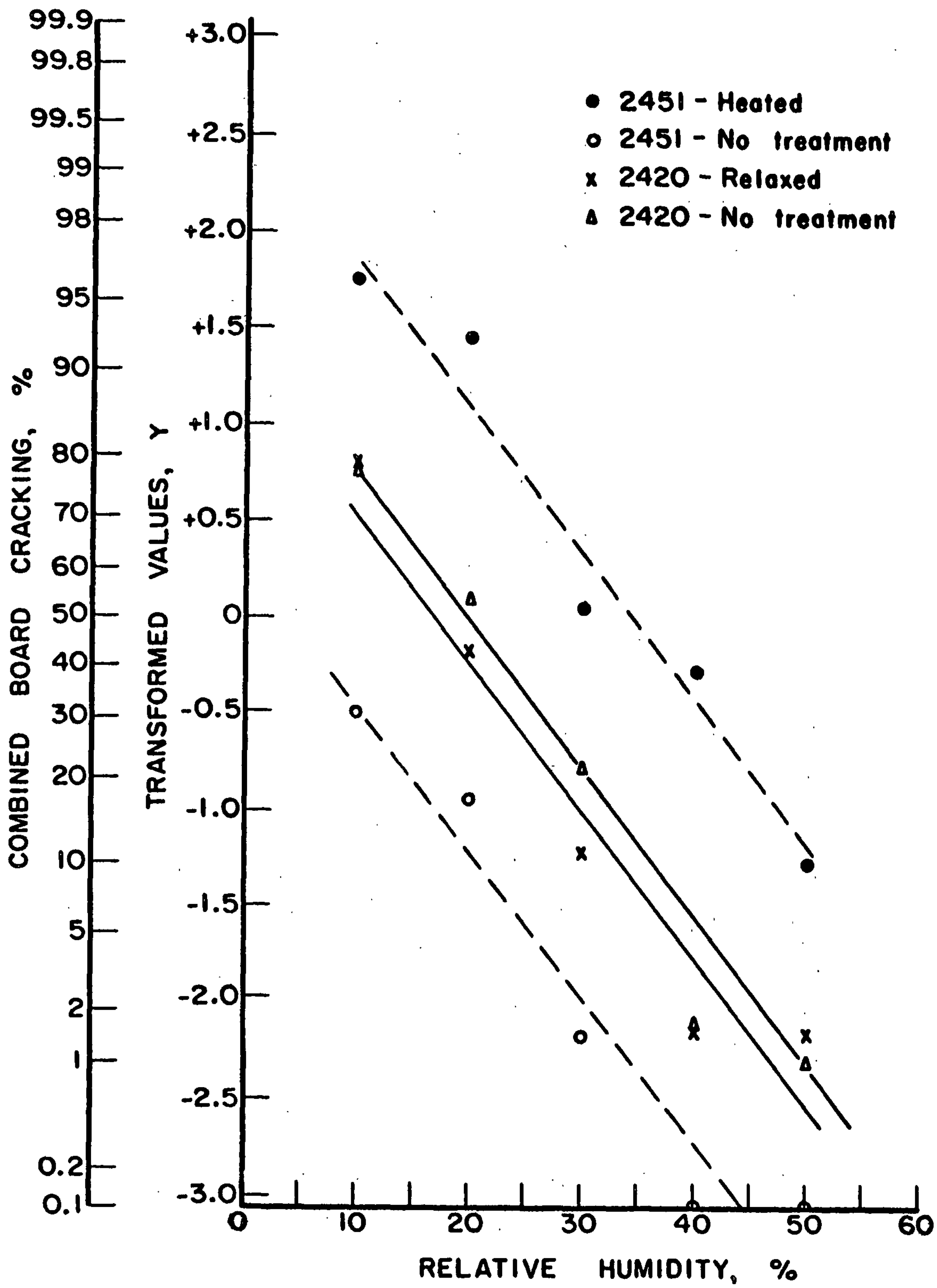

Figure 6. Effect of R.H. on Combined Board Cracking For Samples 2420 and 2457 (Arithmetic Probability Coordinates)

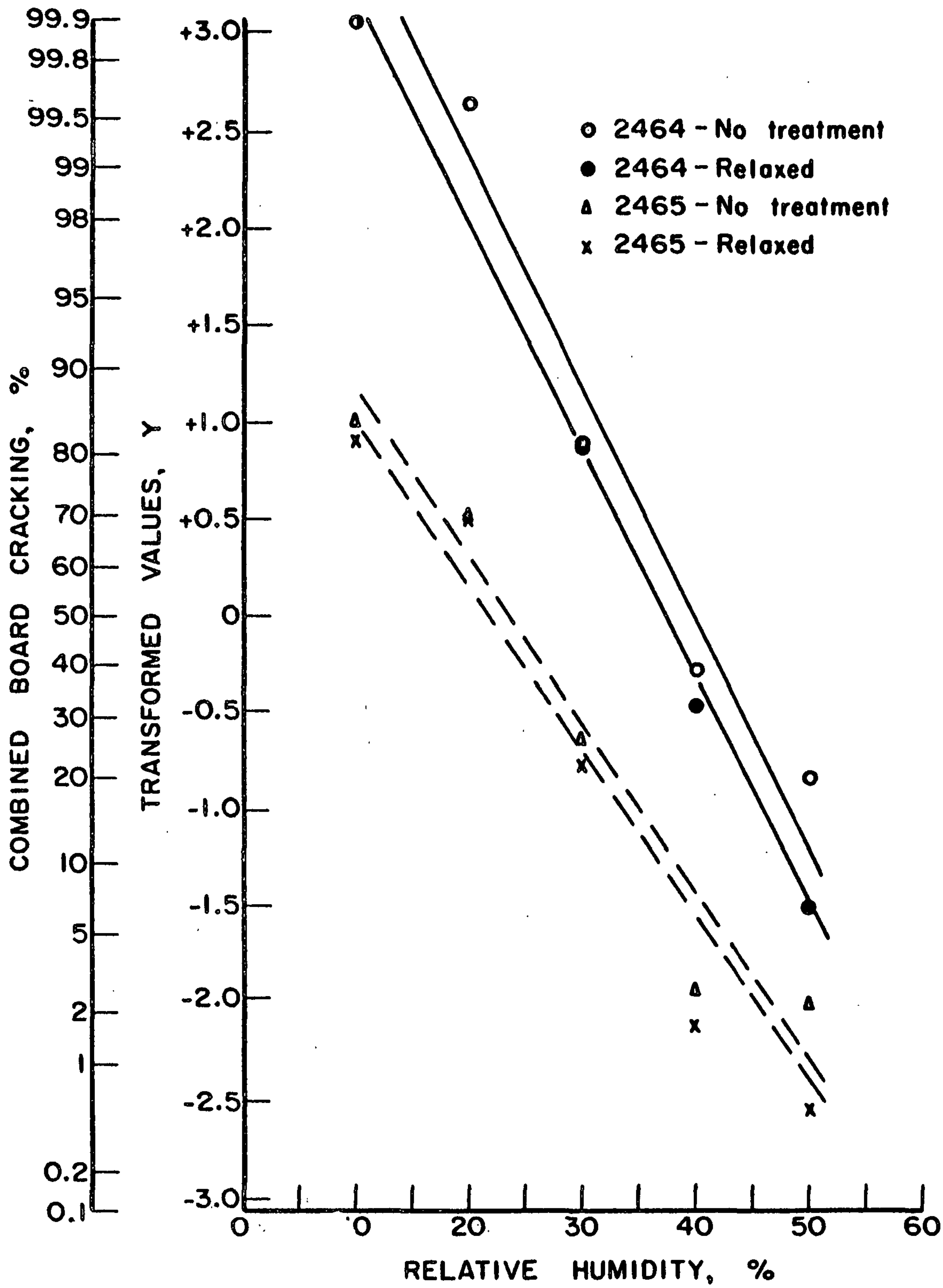

Figure 7. Effect of R.H. on Combined Board Cracking For Samples 2464 and 2465 (Arithmetic Probability Coordinates)

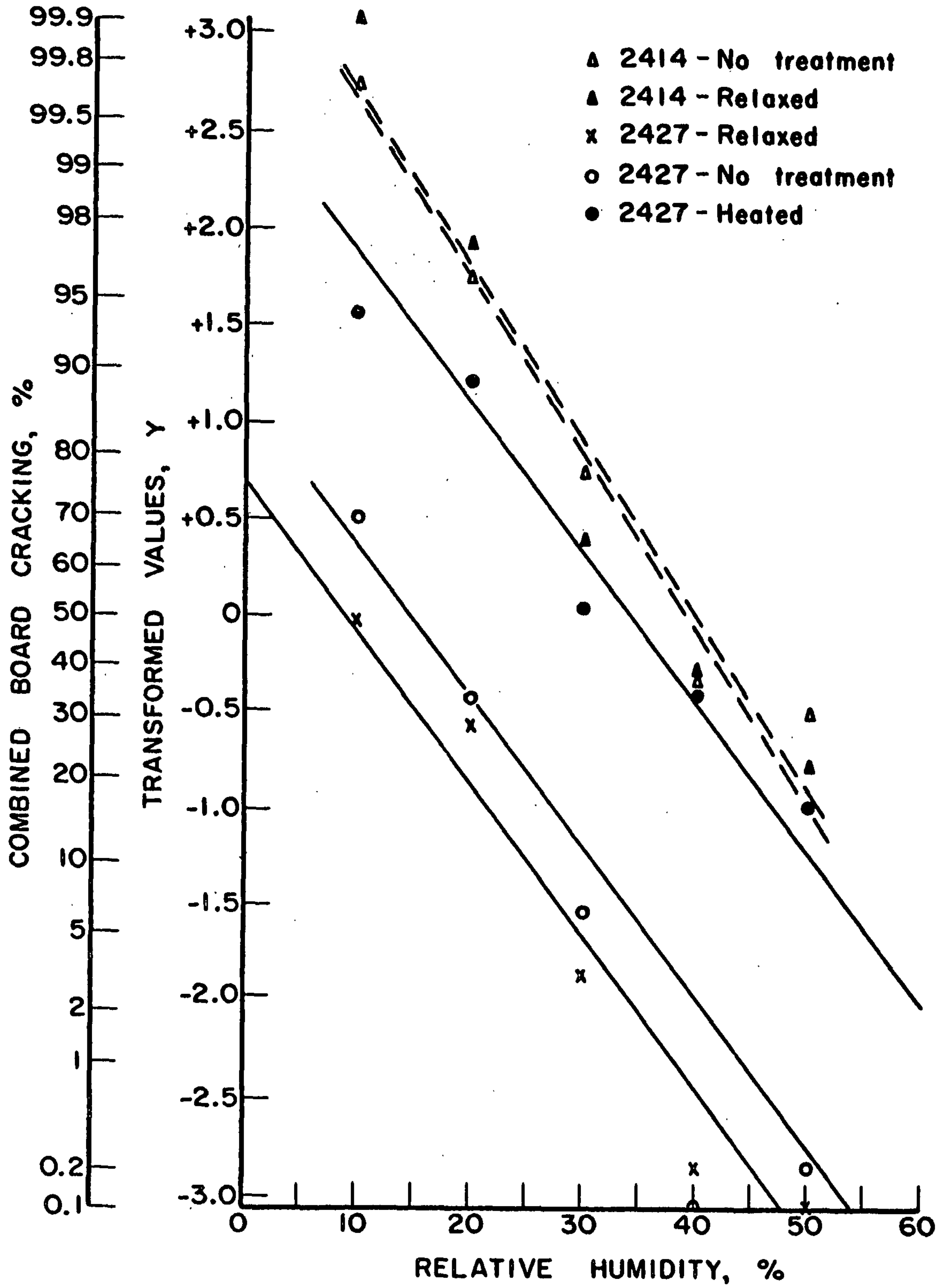

Figure 8. Effect of R.H. on Combined Board Cracking For Samples 2414 and 2427 (Arithmetic Probability Coordinates)

1. In linear coordinates the relationship of combined board cracking and relative humidity was markedly nonlinear.

2. In semilogarithmic and arithmetic probability coordinates more nearly linear relationships between combined board cracking and humidity were obtained.

On this basis, a statistical analysis was carried out for each sample using two types of regression function. They were (a) exponential: $p = a\,(10)^{bx}$ or $\log p = \log a + br$ and (b) probability: $Y = c + dr$ combined board cracking, %.

where p = Combined board cracking, %
Y = combined board cracking, % transformed to standard deviation units

(Note: The transformed values may be found in Appendix I.)

r = R.H., %

a, b, c, d = constants

In carrying out the transformation to normal deviate values, any table tabulating areas under the normal curve may be used. Such tables may be found in most statistical texts. Table A in Appendix III of Reference (3) was convenient and was used in this study.

Referring to Table III, it may be noted that either type of function appeared to give good fits to the data in terms of correlation coefficient. In general, however, the better correlation coefficients were obtained with the probability function. In this connection, it is particularly interesting to note that the slopes of the regression lines for the probability function were nearly equal for all samples except 2464—a laminated board sample, whose tensile

TABLE III

RELATIONSHIPS BETWEEN COMBINED BOARD CRACKING AND RELATIVE HUMIDITY

		Probability[a]			Exponential[b]		
Sample	Data Subdivision	Intercept	Slope	Correlation Coefficient	Intercept	Slope	Correlation Coefficient
2414	Untreated	3.458	−0.0858	−0.98	2.21387	−0.0143	−0.95
	Relaxed	3.857	−0.0997	−0.98	2.26322	−0.0173	−0.97
	Combined	3.658	−0.0928	−0.98	2.23854	−0.0158	−0.95
2420	Untreated	1.629	−0.0837	−0.98	2.61738	−0.0528	−0.96
	Relaxed	1.370	−0.0786	−0.97	2.44817	−0.0486	−0.97
	Combined	1.500	−0.0812	−0.98	2.53278	−0.0507	−0.96
2427	Untreated	1.346	−0.0944	−0.96	2.77353	−0.0761	−0.93
	Relaxed	0.844	−0.0844	−0.98	2.64752	−0.0753	−0.98
	After heating	2.315	−0.0675	−0.99	2.25797	−0.0194	−0.97
	Combined	1.502	−0.0821	−0.78	2.55967	−0.0569	−0.73
2451	Untreated	0.238	−0.0734	−0.96	2.33996	−0.0722	−0.96
	After heating	2.685	−0.0781	−0.98	2.35398	−0.0234	−0.92
	Combined	1.462	−0.0758	−0.67	2.34697	−0.0478	−0.62
2464	Untreated	4.345	−0.1081	−0.98	2.30229	−0.0181	−0.93
	Relaxed	4.847	−0.1277	−0.97	2.50811	−0.0288	−0.89
	Combined	4.596	−0.1179	−0.97	2.40520	−0.0234	−0.87
2465	Untreated	1.953	−0.0857	−0.98	2.56586	−0.0458	−0.95
	Relaxed	2.065	−0.0857	−0.98	2.57733	−0.0486	−0.93
	Combined	2.009	−0.0909	−0.98	2.57160	−0.0472	−0.94
2491	Untreated	0.766	−0.0800	−0.95	2.52894	−0.0690	−0.92
	Relaxed	0.854	−0.0790	−0.98	2.57937	−0.0669	−0.97
	After heating	2.826	−0.0914	−0.99	2.49146	−0.0328	−0.96
	Combined	1.482	−0.0835	−0.82	2.53326	−0.0563	−0.80
Composite		2.266	−0.0884	−0.72	2.46681	−0.0443	−0.63

[a]Combined board cracking transformed to normal deviate.

[b]Exponential function: Log $\underline{p}$ = Log $\underline{a}$ + $\underline{b}\underline{r}$.

and shear characteristics would be expected to be markedly different from unlaminated boards. The fact that the slopes of the regression lines for the other samples are nearly equal suggests that, for many purposes, a regression line of average slope could be used to represent the change in combined board cracking with relative humidity for all but laminated 90-lb. boards. For this situation, boards of varying characteristics would be represented by lines of equal slope but different intercepts. For example, in Fig. 9 the average regression line is shown together with lines drawn parallel through it to give per cent cracking levels at 30% R.H. of 0.1, 0.5, 1, 2, 5, 10, and 20% cracking. Thus, for example, if it were known that a given sample of board exhibited about 10% cracking at 30% R.H. (or equivalent in moisture content) then the expected degree of cracking at other humidity levels may be read from the graph or computed using the appropriate regression equation and "area" table.

To briefly sum up, an analysis of the relationship between combined board cracking and relative humidity indicated that:

1. Exponential or probability type functions appeared to fit the data well with somewhat higher correlation coefficients being attained with the probability functions.

2. The slopes of the regression lines for the probability-type functions were approximately equal for all samples except the laminated material. This suggests that estimates of cracking for any humidity level (within the range tested) may be made if the degree of cracking at any one humidity level is known.

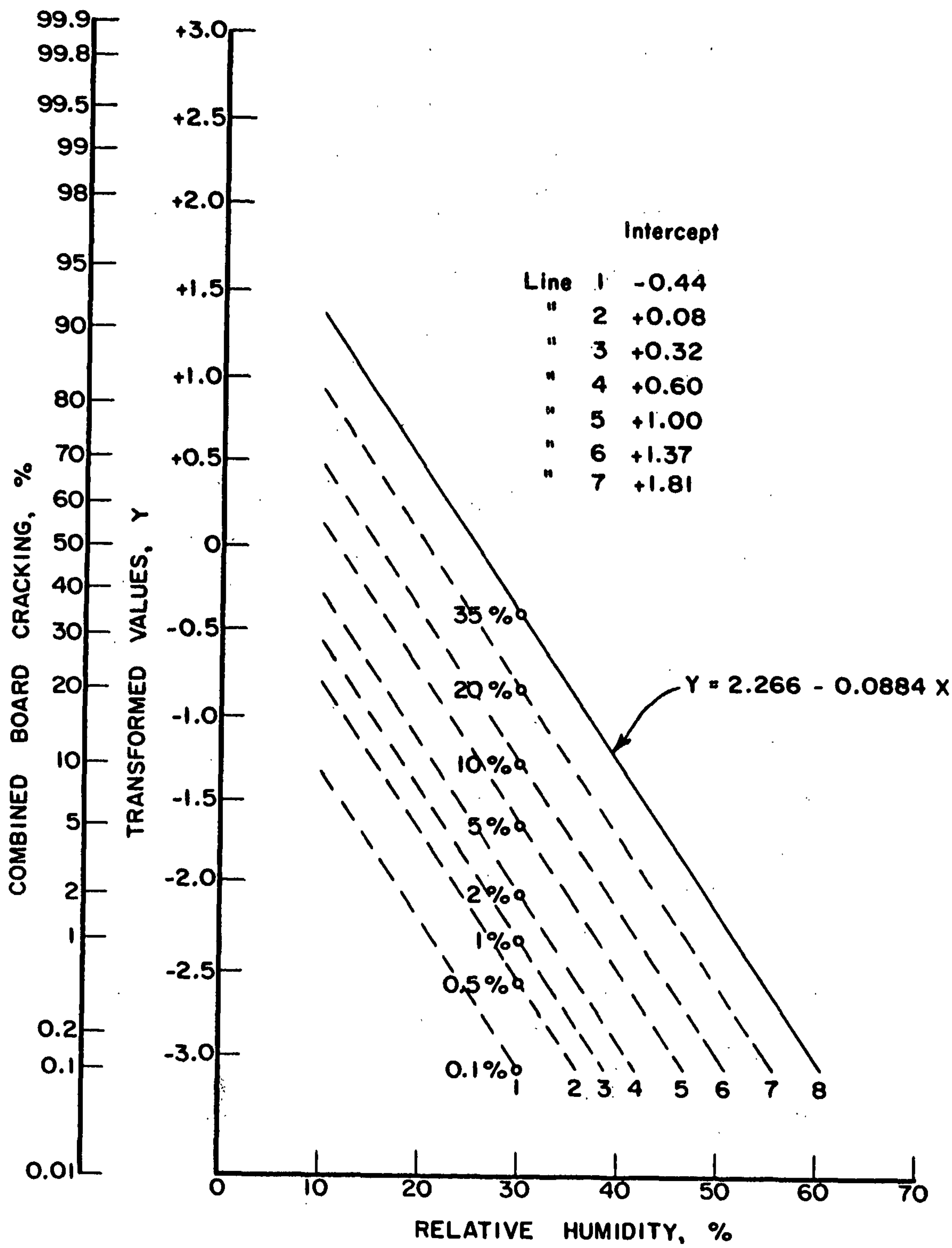

Figure 9. Relationship Between Combined Board Cracking and R.H. For Various Degrees of Cracking at 30% R.H.

RELATIONSHIP BETWEEN COMBINED BOARD AND LINERBOARD CRACKING

The relationships between the linerboard cracking test and combined board cracking were explored using several different types of function. These results are tabulated in Table IV and graphically illustrated in Fig. 10 through 12. In Fig. 10, the results are plotted in linear coordinates; in Fig. 11 semilogarithmic coordinates were used, and in Fig. 12 arithmetic probability coordinates were used. Inspection of the figures suggests that either the exponential or probability coordinates give more nearly linear relationships over the entire range of data.

It may be noted in the figures that the data points for the laminated Sample CS2464 tend to be considerably displaced from the remaining data. This possibly occurs because the shear and tensile characteristics of the laminated board could be expected to differ significantly from the other board samples. Because the linerboard cracking test does not exactly simulate the strains induced during combined board folding, it appears that a separate relationship is required for laminated board samples. For this reason, the results for this sample were treated separately in the analysis.

Referring to Table IV, it may be noted that:

1. The inclusion of nonlinear terms in regressions of the form $\underline{p} = \underline{a} + \underline{bx} + \underline{cx}^2$ ... appeared to significantly improve the correlation (See regressions 1, 2, and 3). These regression equations were regarded, however, as somewhat awkward for predictive purposes.

2. The use of liner cracking angle values to the square or cubic powers in the simple exponential equations also appeared to improve the correlations for the entire data. The use of the angle value squared appeared to

TABLE IV

CORRELATION OF COMBINED BOARD CRACKING AND THE LINERBOARD CRACKING TEST

Regression No.	Data Subdivision	N	Regression Equation	Correlation Coefficient	Type of Function
1	All except laminated[a]	70	$p = 214.2 - 3.0 x$	0.90	Linear
2			$p = 481.3 - 12.2 x + 0.0764 x^2$	0.94	Two factor
3			$p = -153.2 + 21.1 x - 0.494 x^2 + 0.0032 x^3$	0.95	Three factor
4			$\text{Log } p = 5.93 - 0.082 x$	0.89	Exponential
5			$\text{Log } p = 3.57 - 0.00070 x^2$	0.91	Exponential
6			$\text{Log } p = 2.76 - 0.000008 x^3$	0.92	Exponential
7			$Y = 7.68 - 0.141 x$	0.94	Probability
8	10% R.H.[a]	14	$p = 272.5 - 4.21 x$	0.89	Linear
9			$\text{Log } p = 3.13 - 0.003 x$	0.84	Exponential
10			$\text{Log } p = 2.49 - 0.0003 x^2$	0.84	Exponential
11			$Y = 10.03 - 0.192 x$	0.86	Probability
12	20% R.H.[a]	14	$p = 341.7 - 5.28 x$	0.95	Linear
13			$\text{Log } p = 4.0834 - 0.0444 x$	0.94	Exponential
14			$\text{Log } p = 2.9134 - 0.000417 x^2$	0.94	Exponential
15			$Y = 9.71 - 0.175 x$	0.94	Probability
16	30% R.H.[a]	14	$p = 212.8 - 2.96 x$	0.89	Linear
17			$\text{Log } p = 5.3063 - 0.0657 x$	0.90	Exponential
18			$\text{Log } p = 3.3042 - 0.000532 x^2$	0.92	Exponential
19			$Y = 6.14 - 0.111 x$	0.92	Probability
20	40% R.H.[a]	14	$p = 115.9 - 1.58 x$	0.73	Linear
21			$\text{Log } p = 8.0447 - 0.1179 x$	0.88	Exponential
22			$\text{Log } p = 4.1628 - 0.000883 x^2$	0.88	Exponential
23			$Y = 6.37 - 0.125 x$	0.86	Probability
24	50% R.H.[a]	14	$p = 70.55 - 0.943 x$	0.76	Linear
25			$\text{Log } p = 7.2780 - 0.105 x$	0.93	Exponential
26			$\text{Log } p = 3.6708 - 0.000752 x^2$	0.92	Exponential
27			$Y = 4.99 - 0.104 x$	0.91	Probability

TABLE IV (Continued)

CORRELATION OF COMBINED BOARD CRACKING AND THE LINERBOARD CRACKING TEST

Regression	Data Subdivision	$\underline{N}$	Regression Equation	Correlation Coefficient	Type of Function
28	Laminated (2464)	10	$\underline{p} = 248.95 - 3.03\ \underline{x}$	0.87	Linear
29			$\text{Log}\ \underline{p} = 3.4959 - 0.0297\ \underline{x}$	0.79	Exponential
30			$\text{Log}\ \underline{p} = 2.6766 - 0.000260\ \underline{x}^2$	0.82	Exponential
31			$\underline{Y} = 10.60 - 0.158\ \underline{x}$	0.93	Probability

Note: $\underline{p}$ = Combined board cracking, %; $\underline{Y}$ = Combined board cracking, % transformed to standard deviation units.
$\underline{x}$ = Liner cracking angle, °

[a]Results for laminated sample 2464 not included.

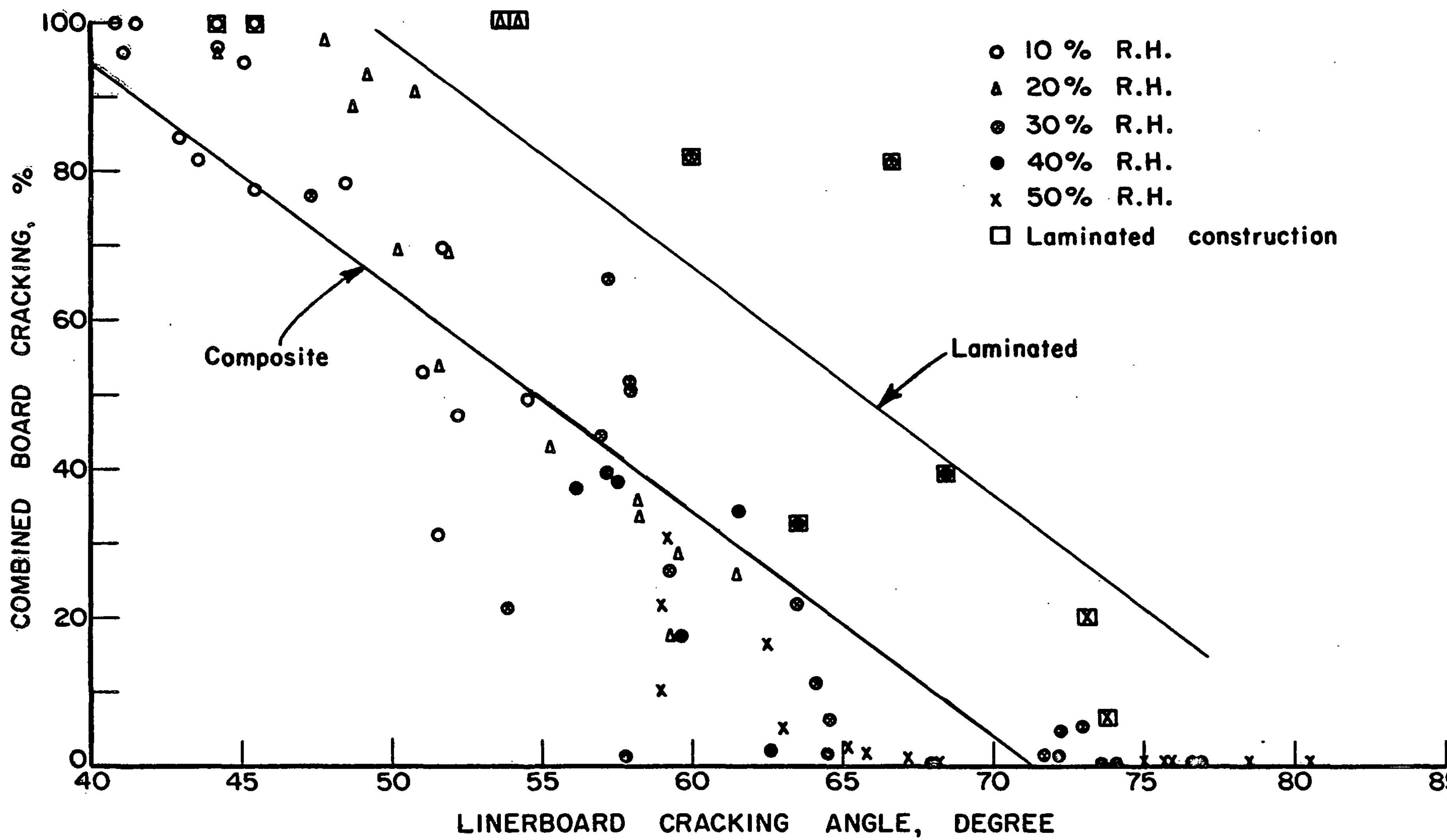

Figure 10. Relationship Between Combined Board Cracking and the Liner Cracking Angle (Linear Coordinates)

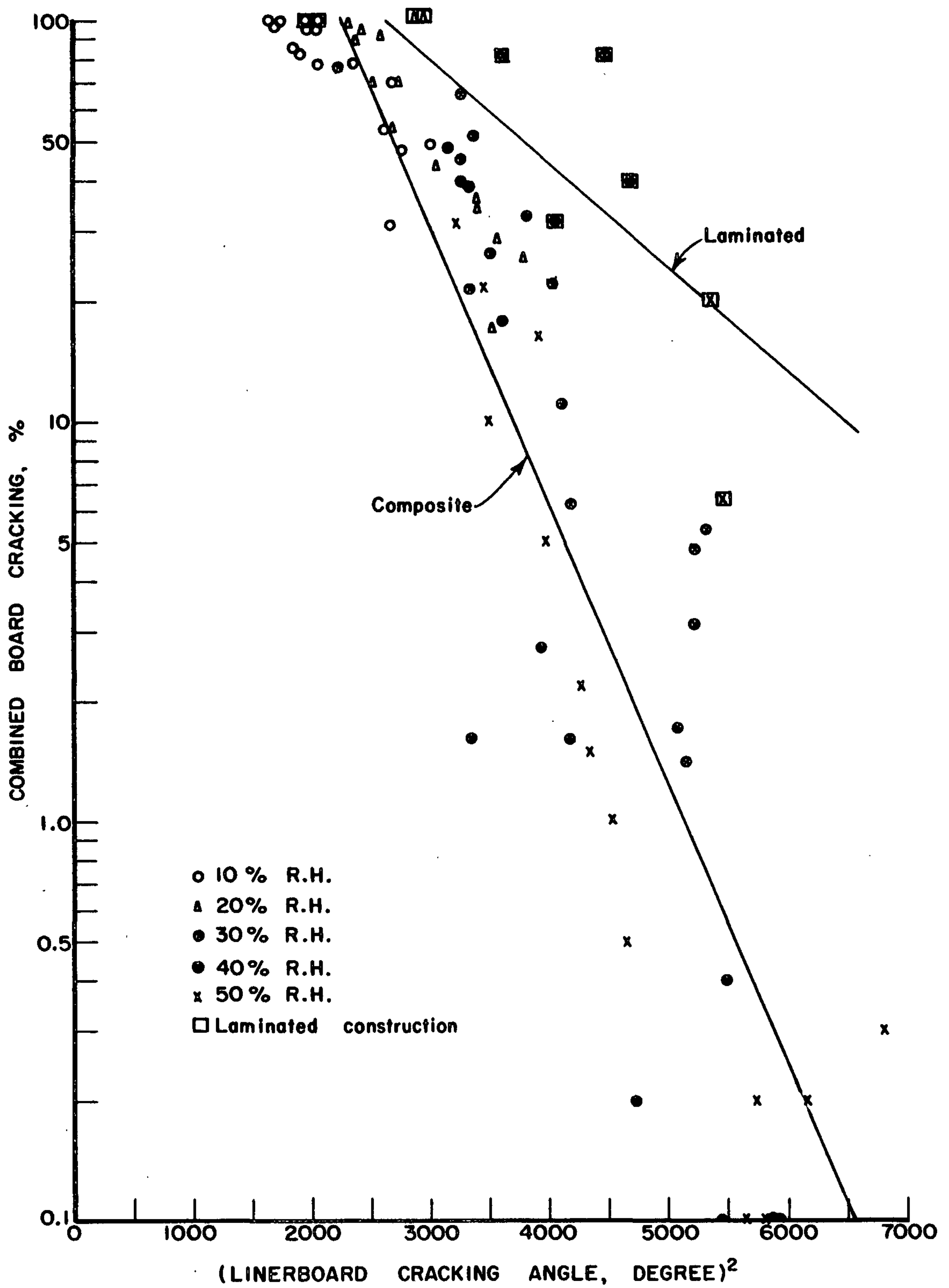

Figure 11. Relationship Between Combined Board Cracking and the Square of the Liner Cracking Angle (Semilogarithmic Coordinates)

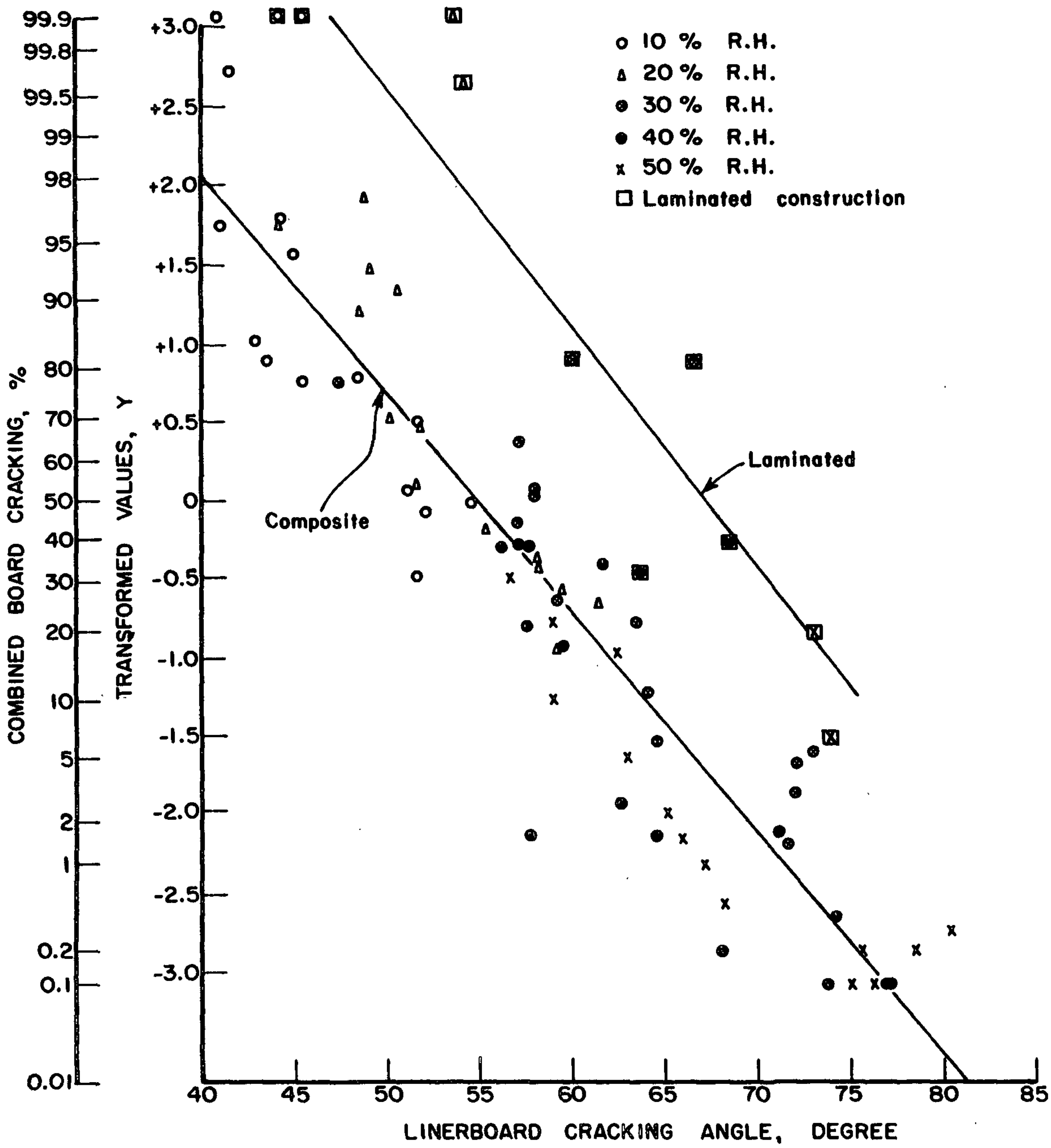

Figure 12. Relationship Between Combined Board Cracking and the Liner Cracking Angle (Arithmetic Probability Coordinates)

give the major improvement in correlation. (See Regressions 4,5, and 6). For the individual humidity levels the differences were often quite slight, however, (see Regressions 9, 10, 13, 14, 17, 18, 21, 22, 25 and 26).

3. In terms of correlation coefficient, none of the functions were markedly inferior. Which to use, therefore, is partly a matter of taste; however, it is thought that the probability function may have the most general application.

Using the graph or regression lines in Table IV for the combined data, estimates were made of the minimum average liner cracking angle required to give combined board having 0.1, 0.5, 1, 2, 5, and 10% cracking. These estimates are shown below.

Minimum Cracking Angle, °

Cracking, %	Linear (Regression 1)	Probability (Regression 7)
0	71	--
0.1	71	76
0.5	71	73
1.0	71	71
2.0	71	69
5.0	70	66
10.0	68	64

Regression 1 implies that a liner cracking angle of about 71° would be sufficient to give no combined board cracking; however, minor amounts of severe cracking were encountered in this study at angles as great as 80°. From this standpoint, Regressions 5 and 7 are probably more realistic. At the other extreme of 10% cracking, the linear equation gives a minimum angle of 68°; however, the graphs indicate no samples exhibiting 10% cracking with liner angles near 70°. In this case, Regression 7 appeared to yield the more realistic estimate. On this basis, Regression 7 may be favored.

Too much attention cannot be given the specific figures mentioned in these examples because of the subjective nature of both the combined board and linerboard evaluation. If other individuals evaluated these or similar samples, it may be anticipated that the results would differ in magnitude from those cited herein; however, it is believed that the trends exhibited by such data would be similar to those reported herein. In addition, it may be desirable to investigate several additional variables in the linerboard tester. They are:

1. Anvil diameter
2. Location of center of rotation
3. Spacing between anvils

Finally, a few tests have suggested that torque <u>vs</u>. angle of rotation measurements may show a peak when the specimen cracks. If so, this would permit converting the test from a subjective to objective evaluation and would have merit when many personnel may be required to perform the evaluations.

As mentioned above, Regression 7 suggests that linerboard having a minimum average rupture angle of 71° may be fabricated into combined board and exhibit no more than about 1% cracking when folded in the same atmosphere in which the liner test was conducted. The degree of combined board cracking in

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3. Grant, E. L. Statistical quality control. 1st Ed. New York, McGraw Hill Book Co., 1946.

THE INSTITUTE OF PAPER CHEMISTRY

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other atmospheres may be estimated using the combined board cracking _vs_. R.H. relationships previously developed. For example, if the liner cracking test (71° average) was conducted at 30% R.H., then line 3 in Fig. 9 would indicate that the cracking at 20% R.H. would be near 7 or 8%. For the same test average but at 47% R.H., line 7 in Fig. 9 indicates the cracking at 20% R.H. would be near 51-52%. Thus, the two analyses complement each other.

To briefly summarize, the data of this study appeared to indicate that:

1. The linerboard cracking test devised at the Institute may be a practical means for evaluating the cracking potential of linerboard because it appears to be significantly related to combined board cracking. Recommendations with regard to possible improvements are mentioned in the text.

2. The relationship between combined board cracking and relative humidity was such that a probability-type equation appeared to fit the data reasonably well.

3. Exponential or probability-type equations appeared to best fit the liner cracking _vs_. combined board cracking data. While either may be used, the probability form is preferred at this time.

4. Separate relationships between combined board cracking and the liner cracking angle appeared to be required for unlaminated and laminated 90-lb. boards. It is hypothesized that this is due to a probable difference in shear characteristics for the two types of board.

APPENDIX I

COMBINED BOARD CRACKING PERCENTAGES TRANSFORMED TO NORMAL DEVIATE VALUES

Sample No.	Combined Board Cracking, Transformed[b] 10	20	30	40	50
2414	+2.75	+1.76	+0.73	−0.32	−0.50
2420	+0.75	+0.09	−0.80	−2.12	−2.33
2427	+0.51	−0.43	−1.54	−3.09	−2.88
2451	−0.49	−0.95	−2.20	−3.09	−3.09
2464	+3.09	+2.65	+0.90	−0.28	−0.85
2465	+1.01	+0.52	−0.64	−1.93	−2.05
2491	+0.08	−0.75	−1.66	−3.09	−2.75
After High Humidity Relaxation Treatment					
2414	+3.09	+1.93	+0.39	−0.30	−0.78
2420	+0.78	−0.18	−1.23	−2.14	−2.17
2427	−0.02	−0.58	−1.87	−2.88	−3.09
2464	+3.09	+3.09[a]	+0.88	−0.46	−1.52
2465	+0.90	+0.51	−0.78	−2.14	−2.58
2491	−0.07	−0.37	−1.61	−2.65	−2.88
After Drying At 125°C. for 36 Hours					
2427	+1.58	+1.22	+0.04	−0.41	−0.98
2451	+1.75	+1.47	+0.05	−0.28	−1.28
2491	+1.80	+1.33	−0.14	−0.93	−1.64

[a] Arbitrarily taken as equal to 99.9%.

[b] Transformed to normal deviate values using statistical table giving area under normal curve. (3).

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

EVALUATION OF THE IMPROVED LINERBOARD CRACKING TESTER USING 69-POUND LINERS

Project 1108-29

Report Three

A Preliminary Report

to

TECHNICAL COMMITTEE
FOURDRINIER KRAFT BOARD INSTITUTE, INC.

November 19, 1963

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

EVALUATION OF THE IMPROVED LINERBOARD CRACKING TESTER USING 69-POUND LINERS

SUMMARY

Two previous reports have discussed the development of a tester for evaluating the score cracking potential of linerboard. Essentially, the test consists of folding the board over an anvil of known radius to induce tensile strains on the outside surface. The angle at which cracking is observed is measured. In the previous report a number of 90-pound liner samples were evaluated for their cracking angle and for their degree of cracking when used as the double-face liner of A-flute combined board. In general, it was noted that: a) the linerboard cracking tests appeared to be reasonably well related to the degree of combined board cracking, and b) useful relationships between the degree of combined board cracking and relative humidity were obtained.

The above work has been extended to a series of 69-pound liner samples in this report with essentially the same results although slightly different regression lines of the probability type were required for the two grades.

If work in progress involving 42-pound liners also gives encouraging results it is suggested that plans be made to:

1. Produce a number of working models of the tester for mill trial.

2. Continue investigations into the variables of the tester and the nature and magnitude of the strains induced in the folding operation of combined board.

3. To investigate the fiber and sheet characteristics which influence the foldability of linerboard.

INTRODUCTION

The initial results obtained in this study were described in Report 1 dated June 18, 1963. In general, attention was focused on a foldability tester of Institute design for determining the cracking potential of linerboard. The initial results indicated that the new tester exhibited some promise; however, additional requirements appeared desirable to permit better evaluations within individual grades of linerboard.

Improved clamps were made for the tester and the anvil heads over which the specimen is stretched were machined to have a 0.010-inch radius. Report 2 dated Sept. 12, 1963 discussed results obtained with the improved tester. In Report 2, 90-pound liner samples were evaluated as double-face liners and after lamination to single-faced board having a 90-pound liner. After scoring and folding, the degree of cracking of the combined board and the liner cracking angle were determined at 10, 20, 30, 40, and 50% R.H. Reasonably favorable correlation between combined board cracking and the liner cracking evaluations with the improved tester were obtained. In addition, analyses of the relationship between combined board cracking and relative humidity indicated that probability-type equations appeared to fit the data trends.

To gain further experience with the tester, it was thought desirable to carry out a similar analysis using 69 and 42-pound liners. As in Report 2, the range of cracking was increased by subjecting the linerboards before fabrication to heat or humidity to change their characteristics. Results obtained with the 69-pound liner samples are briefly summarized in this report.

MATERIALS

The physical characteristics of the 69-pound liner samples used are tabulated in Table I.

TABLE I

PHYSICAL CHARACTERISTICS OF 69-POUND LINER SAMPLES

Sample No.	Basis Weight, lb./M ft.	Caliper, pt.	Tensile, lb./in. In	Tensile, lb./in. Cross	Stretch, % In	Stretch, % Cross
2413	70.4	20.0	114.2	55.3	1.5	3.5
2419	69.3	20.0	130.6	55.6	1.8	4.8
2422	69.4	19.6	113.1	55.6	1.3	2.0
2426	72.4	19.9	126.4	62.2	1.9	3.3
2446	73.7	20.2	116.2	60.9	1.7	3.3
2459	69.5	21.8	118.0	55.2	1.8	3.8
2463	69.6	22.5	124.7	58.6	1.8	4.3
2489	73.0	20.9	130.0	59.0	1.6	3.0

All of the above samples were fabricated into double-faced board and evaluated for cracking at 10, 20, 30, 40, and 50% R.H. In addition, portions of each sample were treated as follows prior to the double-facing operation:

1. At least 72 hours exposure to 90% R.H. and 73°F. followed by preconditioning at less than 35% R.H. and conditioning at 50% and 73°F. prior to fabrication or evaluation.

2. At least 36 hours exposure at 125°C. followed by preconditioning and conditioning as noted in (1) above.

DOUBLE-FACING AND SCORING

Double-faced board was made by hand gluing sheets of the linerboard to a single-faced board corrugated on the Institute's experimental corrugator.

With the exception that a 90-pound liner was used as the single-face liner, the same conditions were used as specified in Report One.

FOLDING

As in the previous work, five sheets of board with 3-11 inch long panel scores per sheet were evaluated for cracking for each sample in each atmosphere. Thus, each percentage cracking value is based on an examination of 165 inches of scoreline. The folded board was taped together to standardize the viewing and handling conditions and the cumulative length of severe cracks was measured—a minimum length of 0.10 inch was used corresponding to a minimum percentage cracking of about 0.1%.

To increase crack visibility, a spray coating of flat black paint was used as described in the previous study. The length and occurrence of severe cracks was judged in comparison with a reference scoreline.

LINERBOARD FOLDABILITY TEST

Ten specimens of each linerboard sample were evaluated at each humidity level with the fold line at right angles to the machine direction. As in the case of the combined board samples, a spray coating of flat black paint was used to increase crack visibility. The rupture angle associated with the first appearances of a crack in the liner surface was measured. Efforts were also made to measure the angle associated with a more severe degree of cracking; however, these readings would have been in excess of the maximum angle permitted by the tester in the higher humidities. Therefore, the severe cracking criterion was discontinued; however, it may be tried in future work in an effort to improve and simplify the routine evaluation of linerboard.

DISCUSSION OF RESULTS

A tabulation of the combined board and linerboard cracking results may be found in Table II. As in the previous study both the combined board and linerboard tests exhibit the expected trends with folding humidity and fabrication treatment. For example, with increasing folding humidity, the degree of combined board cracking decreases and the linerboard cracking angle increases. Similarly, the samples heated at 125°C. prior to fabrication into combined board tended to exhibit increased combined board cracking and smaller linerboard cracking angles relative to the untreated samples.

RELATIONSHIP BETWEEN COMBINED BOARD CRACKING AND LINERBOARD CRACKING

In the previous report it was found that probability or exponential equations appeared to best fit the relationship between combined board cracking and the liner cracking angle. With this in mind, the combined board cracking data in per cent were transformed to standard deviation units (Y). The transformed values are tabulated in Appendix I. (Note: All 0% combined board cracking results were excluded from the analysis because they cannot be transformed into logarithms or standard deviation units.)

A comparison of linear, exponential, and probability-type correlations may be found in Table III for the 69-pound liner data. As may be noted in the table, the probability-type regression exhibited the best correlation with combined board cracking. A graph of the results in arithmetic probability type co-ordinates is shown in Fig. 1. As may be noted in Fig. 1, the overall regression line for the 69-pound liner data is slightly displaced from the regression

TABLE II

COMBINED BOARD AND LINERBOARD CRACKING RESULTS
(Black coated)

Sample No.	Combined Board Cracking, % 10% R.H.	20% R.H.	30% R.H.	40% R.H.	50% R.H.	Linerboard Cracking Angle, ° 10% R.H.	20% R.H.	30% R.H.	40% R.H.	50% R.H.
Untreated										
2413	34.4	10.7	2.3	0.0	0.0	54.5	58.1	64.3	67.3	85.7
2419	31.0	9.4	1.2	0.1	0.0	51.2	56.6	62.4	65.6	75.4
2422	79.6	42.2	12.0	0.8	0.1	48.0	52.5	58.5	62.5	71.5
2426	23.3	9.8	0.6	0.1	0.0	51.4	59.0	64.6	70.4	82.9
2446	61.5	37.5	4.2	0.7	0.3	48.3	54.4	59.7	61.7	77.0
2459	52.0	19.0	5.7	0.1	0.0	49.7	54.7	60.4	63.5	76.0
2463	41.4	13.8	2.2	0.0	0.0	49.2	55.0	59.8	65.5	79.3
2489	79.2	45.9	10.9	2.0	0.2	46.5	49.6	57.4	63.4	76.4
After High Humidity Relaxation Treatment										
2413	44.2	10.6	0.7	0.0	0.0	53.1	56.3	64.9	68.1	79.6
2419	30.4	4.2	0.9	0.0	0.0	54.4	56.4	66.8	71.9	74.7
2422	80.0	50.0	9.8	1.0	0.1	50.6	53.7	60.4	64.2	68.5
2426	29.3	3.1	0.3	0.0	0.0	55.9	60.4	69.3	72.0	81.3
2446	53.8	24.6	2.7	0.1	0.1	49.8	56.3	62.8	65.1	71.9
2459	76.3	31.3	1.6	0.3	0.0	51.3	57.9	66.6	71.7	78.5
2463	63.4	10.3	0.4	0.0	0.0	51.9	58.5	67.8	68.9	77.4
2489	82.8	37.4	6.6	1.8	0.0	50.8	57.7	61.8	62.6	75.1
After Drying at 125°C. for 36 hr.										
2413	87.4	36.9	14.4	2.5	0.4	47.2	51.2	57.6	63.4	71.1
2419	66.6	27.2	8.0	0.8	0.1	48.0	52.7	56.1	60.4	67.9
2422	93.2	71.7	34.3	8.5	1.5	44.7	53.2	56.1	56.9	68.9
2426	66.6	43.0	5.4	2.6	0.4	47.7	54.4	56.7	62.7	67.5
2446	94.3	82.9	49.2	22.2	4.0	42.1	50.3	52.7	56.7	62.3
2459	96.4	74.6	23.4	15.0	1.1	44.2	51.0	54.2	58.3	67.6
2463	84.8	49.3	6.0	0.7	0.0	46.3	51.9	55.8	59.6	72.5
2489	98.1	90.7	36.3	28.7	13.7	40.1	46.4	51.6	52.8	61.5

Note: Linerboard cracking angle corresponding to initial observed crack.

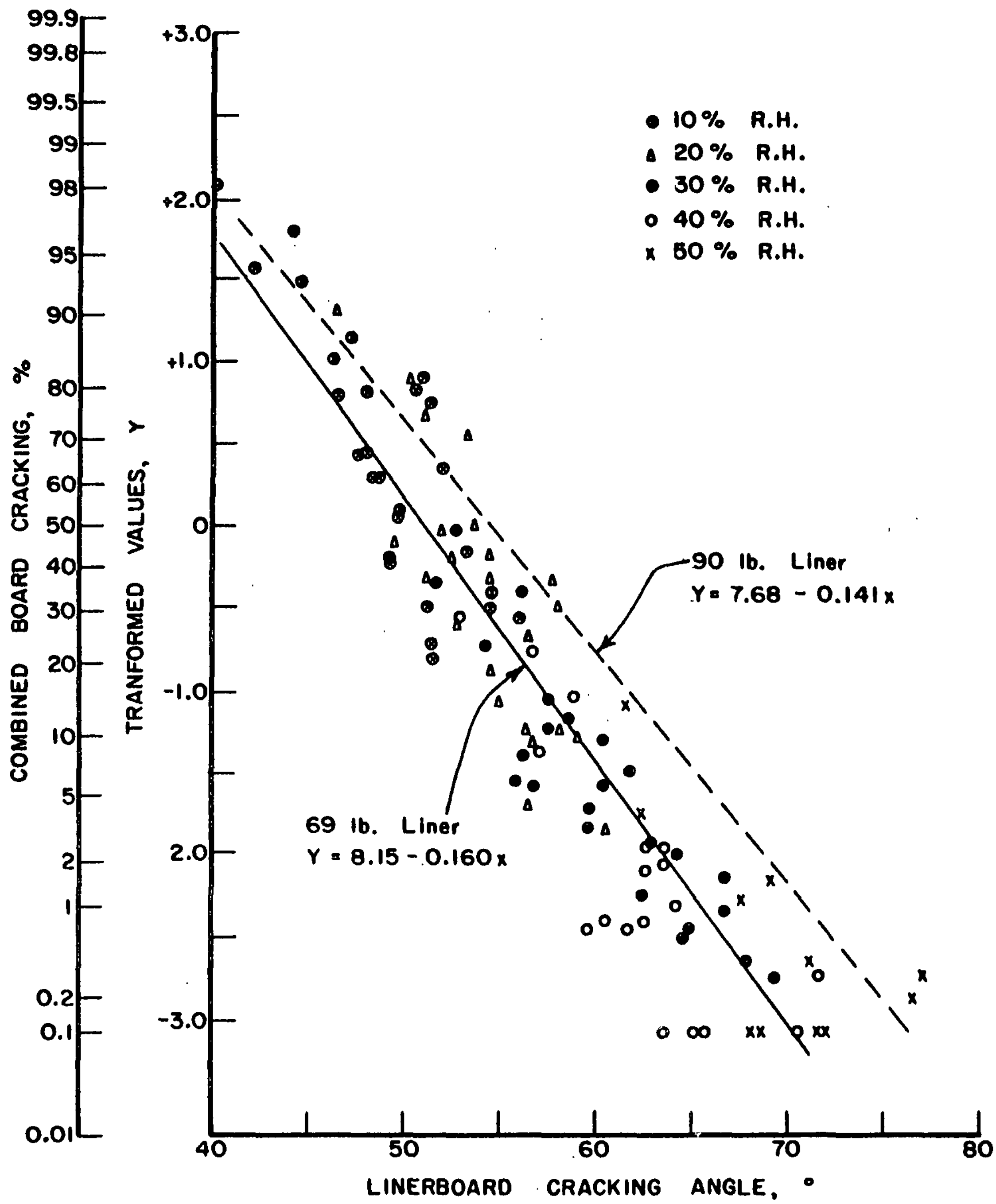

Fig. 1. Relationship Between Combined Board Cracking and the Liner Cracking Angle for 69-Pound Liner Samples (Arithmetic Probability Coordinates)

line for 90-pound liners and exhibits a slightly greater slope. These differences in slope and intercept between the 69 and 90-pound grades may reflect differences in caliper and, probably, shear characteristics. When data for 42-pound double-face liners (testing in progress) are available, it should be possible to clarify this.

TABLE III

CORRELATIONS OF COMBINED BOARD CRACKING
AND THE LINER CRACKING ANGLE

(Composite 69-pound liner results--N = 102)

Equation No.	Type of Equation	Regression Equation	Correlation Coefficient
1.	Linear	$p = 219.1 - 3.33x$	0.85
2.	Exponential	$\text{Log } p = 7.192 - 0.110x$	0.91
3.	Exponential	$\text{Log } p = 4.038 - 0.000,936x^2$	0.91
4.	Probability	$Y = 8.15 - 0.160x$	0.93

Note: p = combined board cracking.

Y = combined board cracking, transformed to standard deviation units.

x = liner cracking angle, °.

The probability-type regressions were also performed using the data at each humidity level. These regressions are shown in Table IV. As may be noted, the correlations at each relative humidity level were reasonably high. They tended to be, however, somewhat lower than were obtained with 90-pound liners. This is probably due to the fact that lesser amounts of cracking tended to be obtained with the 69-pound liners in comparable conditions. This was particularly true at 40 and 50% R.H. where a number of combined board samples exhibited little or no severe cracking. It would be expected that estimates of minor amounts of cracking would be subject to considerable uncertainty.

TABLE IV

CORRELATION OF COMBINED BOARD CRACKING
AND THE LINERBOARD CRACKING TEST

Equation No.	Data Subdivision	N	Regression Equation[a]	Correlation Coefficient
		69-Pound Liners		
1	Overall	102	$\underline{Y} = 8.15 - 0.160\underline{x}$	0.93
2	10% R.H.	24	$\underline{Y} = 8.89 - 0.172\underline{x}$	0.82
3	20% R.H.	24	$\underline{Y} = 10.47 - 0.201\underline{x}$	0.83
4	30% R.H.	24	$\underline{Y} = 6.70 - 0.138\underline{x}$	0.90
5	40% R.H.	18	$\underline{Y} = 6.54 - 0.140\underline{x}$	0.81
6	50% R.H.	12	$\underline{Y} = 3.97 - 0.094\underline{x}$	0.71
		90-Pound Liners[a]		
7	Overall	70	$\underline{Y} = 7.68 - 0.141\underline{x}$	0.94
8	10% R.H.	14	$\underline{Y} = 10.03 - 0.192\underline{x}$	0.86
9	20% R.H.	14	$\underline{Y} = 9.71 - 0.175\underline{x}$	0.94
10	30% R.H.	14	$\underline{Y} = 6.14 - 0.111\underline{x}$	0.92
11	40% R.H.	14	$\underline{Y} = 6.37 - 0.125\underline{x}$	0.86
12	50% R.H.	14	$\underline{Y} = 4.99 - 0.104\underline{x}$	0.91

[a]$\underline{Y}$ = combined board cracking transformed to standard deviation units.

$\underline{x}$ = liner cracking angle, °.

To illustrate in another way the degree of relationship between the liner cracking angle and combined board cracking the over-all regression equations for the 69 and 90-pound liners [Equations (1) and (7) in Table IV] were used to compute percentage combined board cracking values. The calculated and observed values are compared in Tables V and VI for the 69 and 90-pound data, respectively. In general, while large discrepancies occur, reasonable agreement is attained in most instances—particularly with respect to sample ranking and humidity effects.

In brief summary, on the basis of these results, it appears that

1. The linerboard cracking test is reasonably well related to combined board cracking when either 69 or 90-pound liners are used as the double-face liner.

TABLE V

COMPARISON OF COMPUTED AND OBSERVED COMBINED BOARD CRACKING FOR 69-POUND SAMPLES

Sample No.	Combined Board Cracking, % 10% R.H. Calculated[b]	Observed	Diff.	20% R.H. Calculated[b]	Observed	Diff.	30% R.H. Calculated[b]	Observed	Diff.	40% R.H. Calculated[b]	Observed	Diff.	50% R.H. Calculated[b]	Observed	Diff.
							Untreated								
2413	28.4	34.4	-6.0	12.5	10.7	+1.8	1.6	2.3	-0.7	0.4	0.0	+0.4	0.0[a]	0.0	0.0
2419	48.4	31.0	+17.4	18.1	9.4	+8.7	3.4	1.2	+2.2	0.9	0.1	+0.8	0.0[a]	0.0	0.0
2422	68.1	79.6	-11.5	40.1	42.2	-2.1	11.3	12.0	-0.7	3.2	0.8	+2.4	0.0[a]	0.1	-0.1
2426	47.2	23.3	+23.9	9.8	9.8	0.0	1.4	0.6	+0.8	0.1	0.1	0.0	0.0[a]	0.0	0.0
2446	66.3	61.5	+4.8	29.1	37.5	-8.4	8.1	4.2	+3.9	4.3	0.7	+3.6	0.0[a]	0.3	-0.3
2459	57.9	52.0	+5.9	27.4	19.0	+8.4	6.5	5.7	+0.8	2.2	0.1	+2.1	0.0[a]	0.0	0.0
2463	61.0	41.4	+19.6	25.8	13.8	+12.0	7.8	2.2	+5.6	1.0	0.0	+1.0	0.0[a]	0.0	0.0
2489	76.1	79.2	-3.1	58.3	45.9	+12.4	15.2	10.9	+4.3	2.3	2.0	+0.3	0.0[a]	0.2	-0.2
							Relaxed								
2413	36.3	44.2	-7.9	19.5	10.6	+8.9	1.3	0.7	+0.6	0.3	0.0	+0.3	0.0[a]	0.0	0.0
2419	29.1	30.4	-1.3	19.2	4.2	+15.0	0.6	0.9	-0.3	0.0[a]	0.0	0.0	0.0[a]	0.0	0.0
2422	52.0	80.0	-28.0	33.0	50.0	-17.0	6.5	9.8	-3.3	1.7	1.0	+0.7	0.2	0.1	+0.1
2426	21.5	29.3	-7.8	6.5	3.1	+3.4	0.2	0.3	-0.1	0.0[a]	0.0	0.0	0.0[a]	0.0	0.0
2446	57.1	53.8	+3.3	19.5	24.6	-5.1	2.9	2.7	+0.2	1.2	0.1	+1.1	0.0[a]	0.1	-0.1
2459	47.6	76.3	-28.7	13.4	31.3	-17.9	0.6	1.6	-1.0	0.0[a]	0.3	-0.3	0.0[a]	0.0	0.0
2463	44.0	63.4	-19.4	11.3	10.3	+1.0	0.4	0.4	0.0	0.2	0.0	+0.2	0.0[a]	0.0	0.0
2489	50.8	82.8	-32.0	14.0	37.4	-23.4	4.1	6.6	-2.5	3.1	1.8	+1.3	0.0[a]	0.0	0.0
							Heated								
2413	72.6	87.4	-14.8	48.4	36.9	+11.5	14.2	14.4	-0.2	2.3	2.5	-0.2	0.0[a]	0.4	-0.4
2419	68.1	66.6	+1.5	39.0	27.2	+11.8	20.3	8.0	+12.3	6.5	0.8	+5.7	0.3	0.1	+0.2
2422	84.1	93.2	-9.1	35.9	71.7	-35.8	20.3	34.3	-14.0	17.1	8.5	+8.6	0.2	1.5	-1.3
2426	69.8	66.6	+3.2	29.1	43.0	-13.9	17.9	5.4	+12.5	3.0	2.6	+0.4	0.4	0.4	0.0
2446	92.1	94.3	-2.2	54.0	82.9	-28.9	39.0	49.2	-10.2	17.9	22.2	-4.3	3.4	4.0	-0.6
2459	86.0	96.4	-10.4	49.6	74.6	-25.0	30.2	23.4	+6.8	11.9	15.0	-3.1	0.4	1.1	-0.7
2463	77.0	84.8	-7.8	44.0	49.3	-5.3	21.8	6.0	+15.8	8.2	0.7	+7.5	0.0[a]	0.0	0.0
2489	95.8	98.1	-2.3	76.7	90.7	-14.0	45.6	36.3	+9.3	38.2	28.7	+9.5	4.6	13.7	-9.1

[a]Estimated percentage values less than 0.1 were taken equal to zero.

[b]Calculated from regression equation $\underline{Y} = 8.15 - 0.160\underline{x}$ where $\underline{x}$ is the liner cracking angle and $\underline{Y}$ is combined board cracking in standard deviation units. $\underline{Y}$ values were transformed to percentages using Table A, Appendix III of Reference (1).

TABLE VI

COMPARISONS OF COMPUTED AND OBSERVED COMBINED BOARD CRACKING FOR 90-POUND SAMPLES

Sample No.	Combined Board Cracking, % — 10% R.H. Calculated[b]	10% R.H. Observed	10% R.H. Diff.	20% R.H. Calculated[b]	20% R.H. Observed	20% R.H. Diff.	30% R.H. Calculated[b]	30% R.H. Observed	30% R.H. Diff.	40% R.H. Calculated[b]	40% R.H. Observed	40% R.H. Diff.	50% R.H. Calculated[b]	50% R.H. Observed	50% R.H. Diff.
Untreated															
2414	96.5	99.7	-3.2	92.6	96.1	-3.5	84.4	76.7	+7.7	40.9	37.5	+3.4	37.8	30.9	+6.9
2420	90.0	77.4	+12.6	65.5	53.5	+12.0	33.0	21.2	+11.8	0.9	1.7	-0.8	3.6	1.0	+2.6
2427	65.2	69.5	-4.3	29.8	33.4	-3.6	7.6	6.2	+1.4	0.0[a]	0.1	-0.1	0.0[a]	0.2	-0.2
2451	65.5	31.1	+34.4	24.8	17.1	+7.7	0.8	1.4	-0.6	0.0[a]	0.1	-0.1	0.1	0.1	0.0
2465	94.8	84.4	+10.4	72.6	69.7	+2.9	25.1	26.1	-1.0	12.5	2.7	+9.8	6.5	2.2	+4.3
2491	68.1	53.0	+15.1	16.1	25.6	-9.5	0.6	4.8	-4.2	0.3	0.1	+0.2	0.0[a]	0.3	-0.3
Relaxed															
2414	97.3	99.9	-2.6	82.6	97.3	-14.7	34.8	65.3	-30.5	33.4	38.1	-4.7	26.8	21.8	+5.0
2420	80.5	78.3	+2.2	45.2	42.8	+2.4	8.7	11.0	-2.3	7.9	1.6	+6.3	5.5	1.5	+4.0
2427	49.2	49.3	-0.1	23.6	28.2	-4.5	0.6	3.1	-2.5	2.8	0.2	+2.6	0.2	0.1	+0.1
2465	93.7	81.6	+12.1	64.8	69.4	-4.6	10.2	21.9	-11.7	32.3	1.6	+30.7	2.6	0.5	+2.1
2491	62.6	47.1	+15.5	30.5	35.5	-5.0	0.5	5.4	-4.9	0.3	0.4	-0.1	0.1	0.2	-0.1
Heated															
2427	90.7	94.3	-3.6	79.1	88.9	-9.8	30.8	51.4	-20.6	15.6	34.2	-18.6	12.9	16.3	-3.4
2451	97.0	96.0	+1.0	77.0	92.9	-15.9	31.6	51.9	-20.3	35.6	39.1	-3.5	26.1	10.0	+16.1
2491	92.4	96.4	-4.0	70.2	90.8	-20.6	35.9	44.3	-8.4	23.9	17.6	+6.3	11.5	5.0	+6.5

[a]Estimated percentage values less than 0.1 were recorded as zero.

[b]Calculated from regression equation $\underline{Y} = 7.68 - 0.141x$ where $\underline{x}$ is the liner cracking angle and $\underline{Y}$ is the combined board cracking in standard deviation units. $\underline{Y}$ values were transformed to percentages using Table A, Appendix III of Reference ($\underline{1}$).

2. The relationship between the two quantities—combined board cracking and liner cracking angle—is best fitted by probability-type equations. At this time it appears that slightly different regression constants are required for the two grades.

EFFECT OF HUMIDITY ON COMBINED BOARD CRACKING

In the previous report it was shown that with 90-pound liners the relationship between the degree of combined board cracking and relative humidity was approximately linear when plotted using arithmetic probability coordinates. Similar graphs were prepared for the 69-pound samples of this study as shown in Fig. 2 through 7. Referring to the figures, it may be noted that essentially linear relationships were obtained for all the samples.

As in the previous report the transformed combined board cracking values ($\underline{Y}$) were correlated with relative humidity as shown in Table VII. In general, the slopes were roughly equal for all samples although Sample 2463 exhibited relatively high slopes for the relaxed and heated samples. It may be recalled that the 90-pound Sample 2464 laminated from two 42-pound plies exhibited a greater slope than the remaining samples. As a matter of interest, Sample 2463 was manufactured by the same mill.

A covariance analysis was carried out for a number of the samples to determine if the differences in slope were significant. In all cases examined, the slopes were not significantly different in view of the scatter of the data and the small number of points for each line. A similar analysis was carried out to test the differences in slope between samples with the same result. Thus, there is considerable justification for using an average slope for all the data.

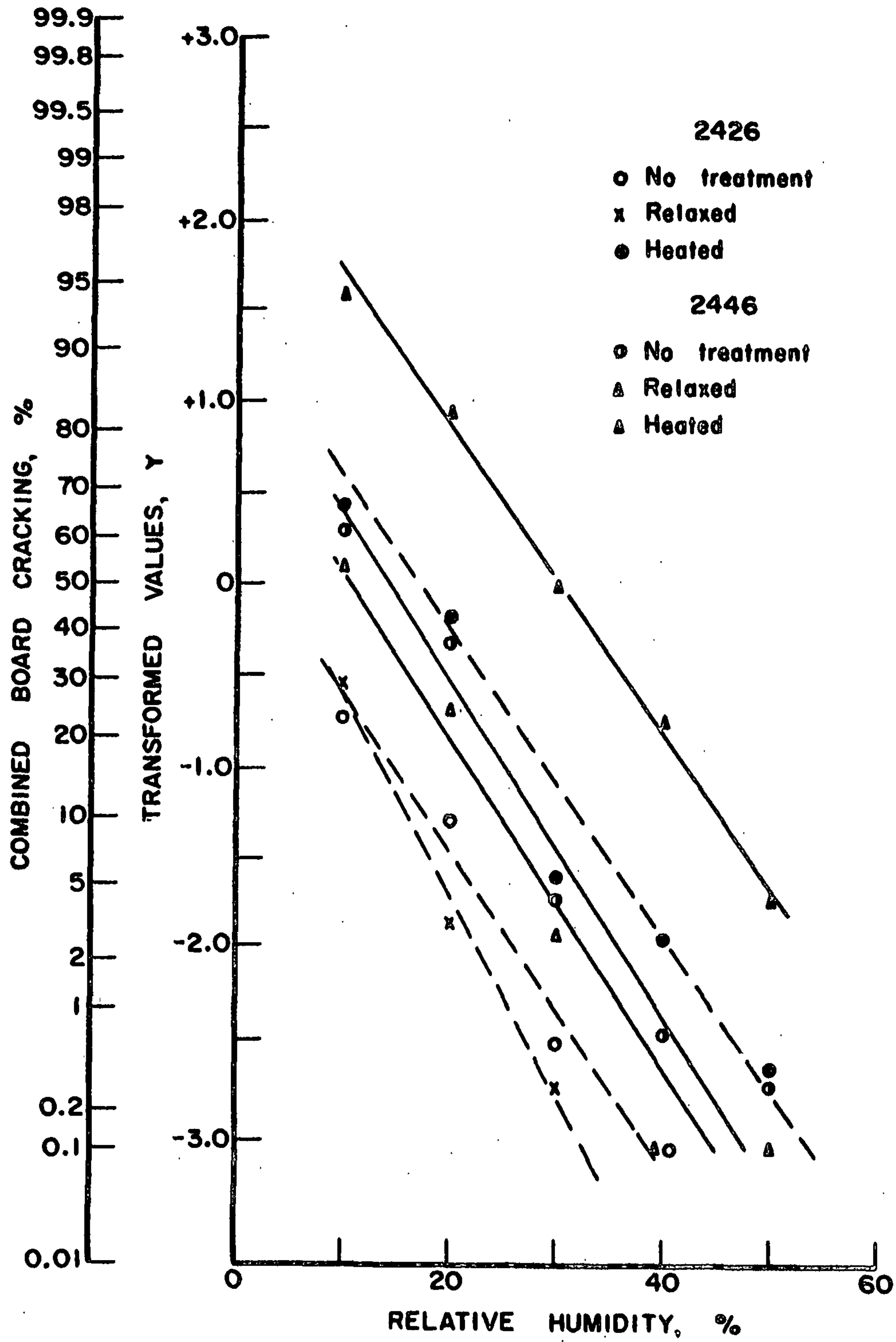

Fig. 2. Effect of Relative Humidity on Combined Board Cracking for Samples 2426 and 2446

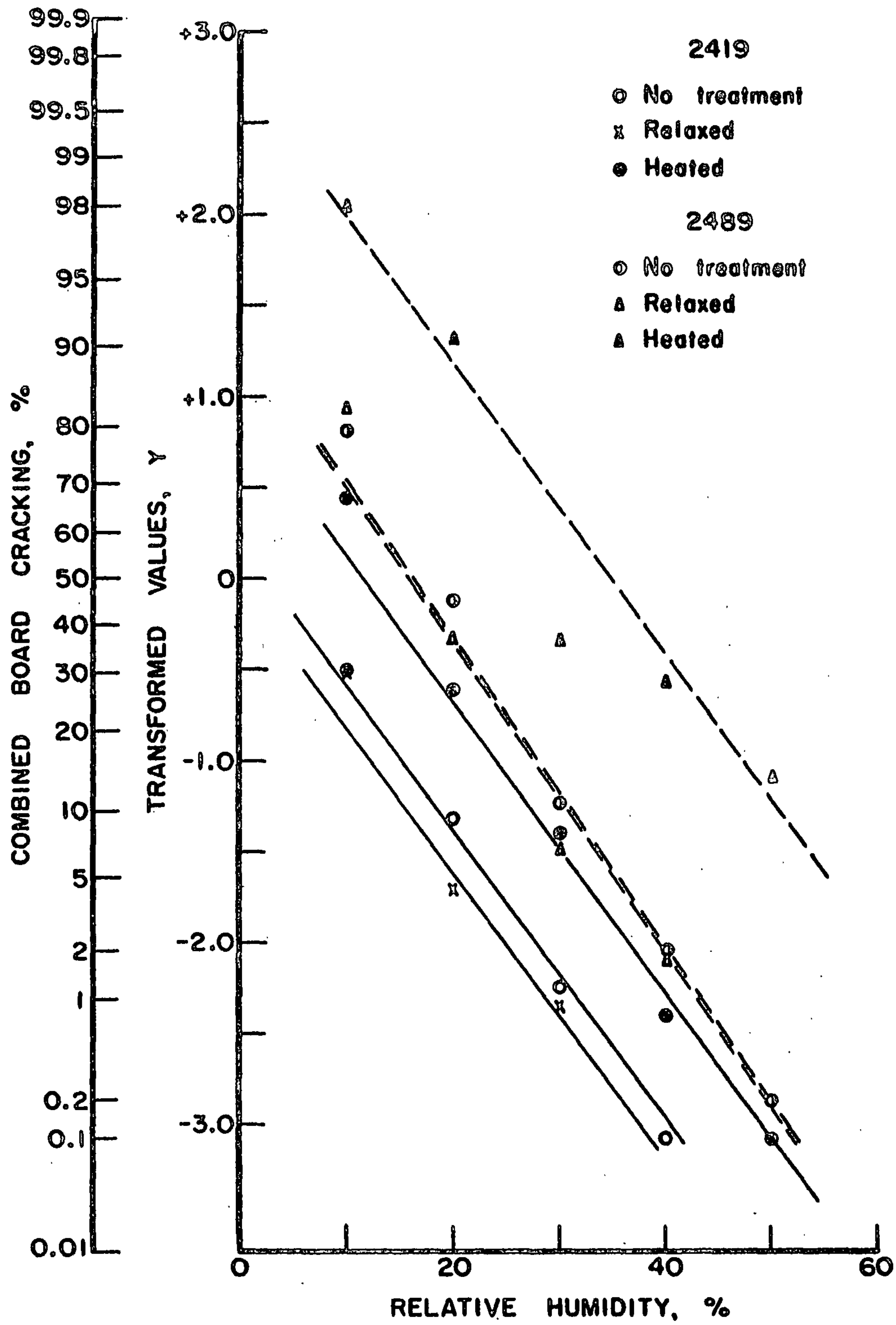

Fig. 3. Effect of Relative Humidity on Combined Board Cracking for Samples 2419 and 2489

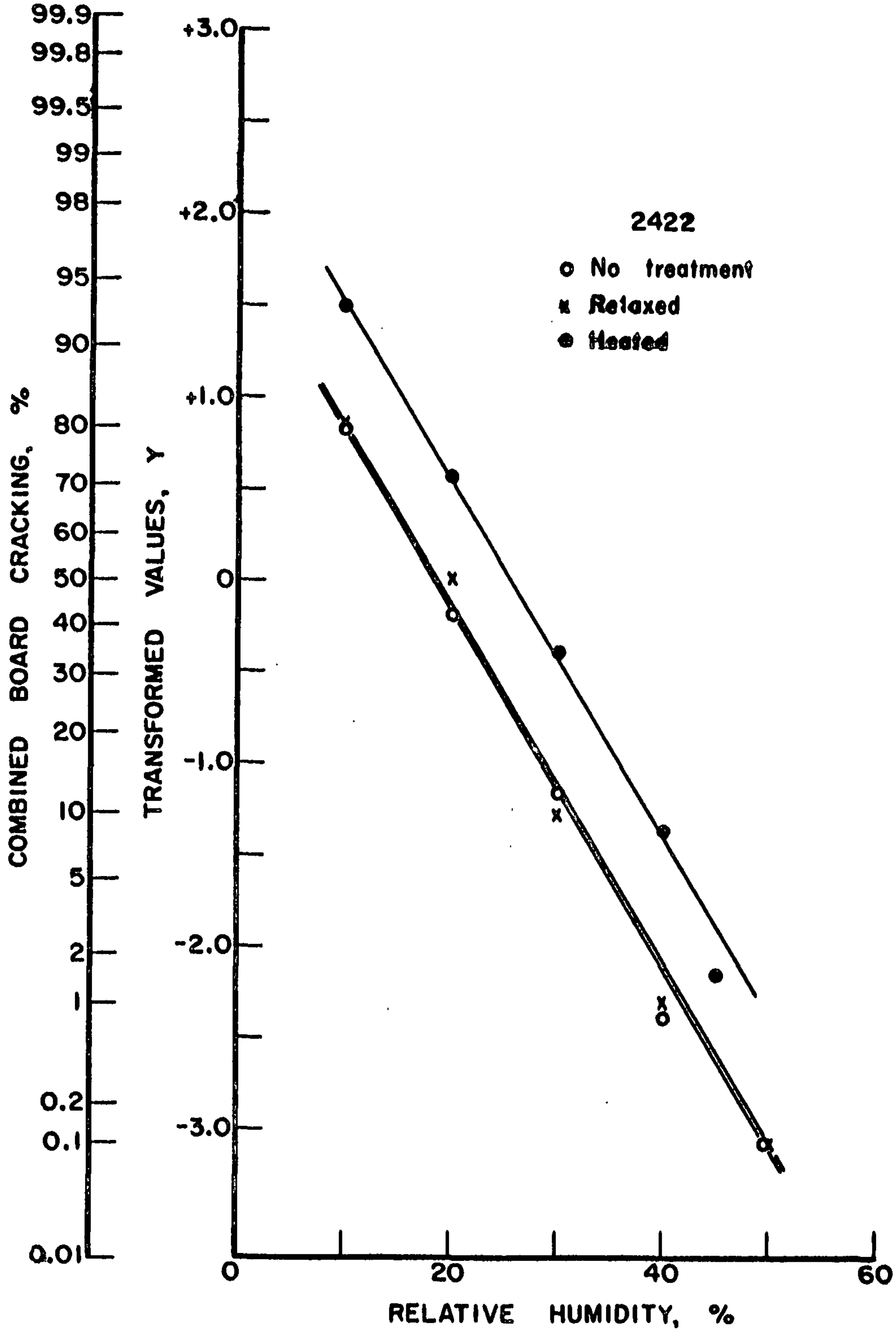

Fig. 4. Effect of Relative Humidity on Combined Board Cracking for Sample 2422

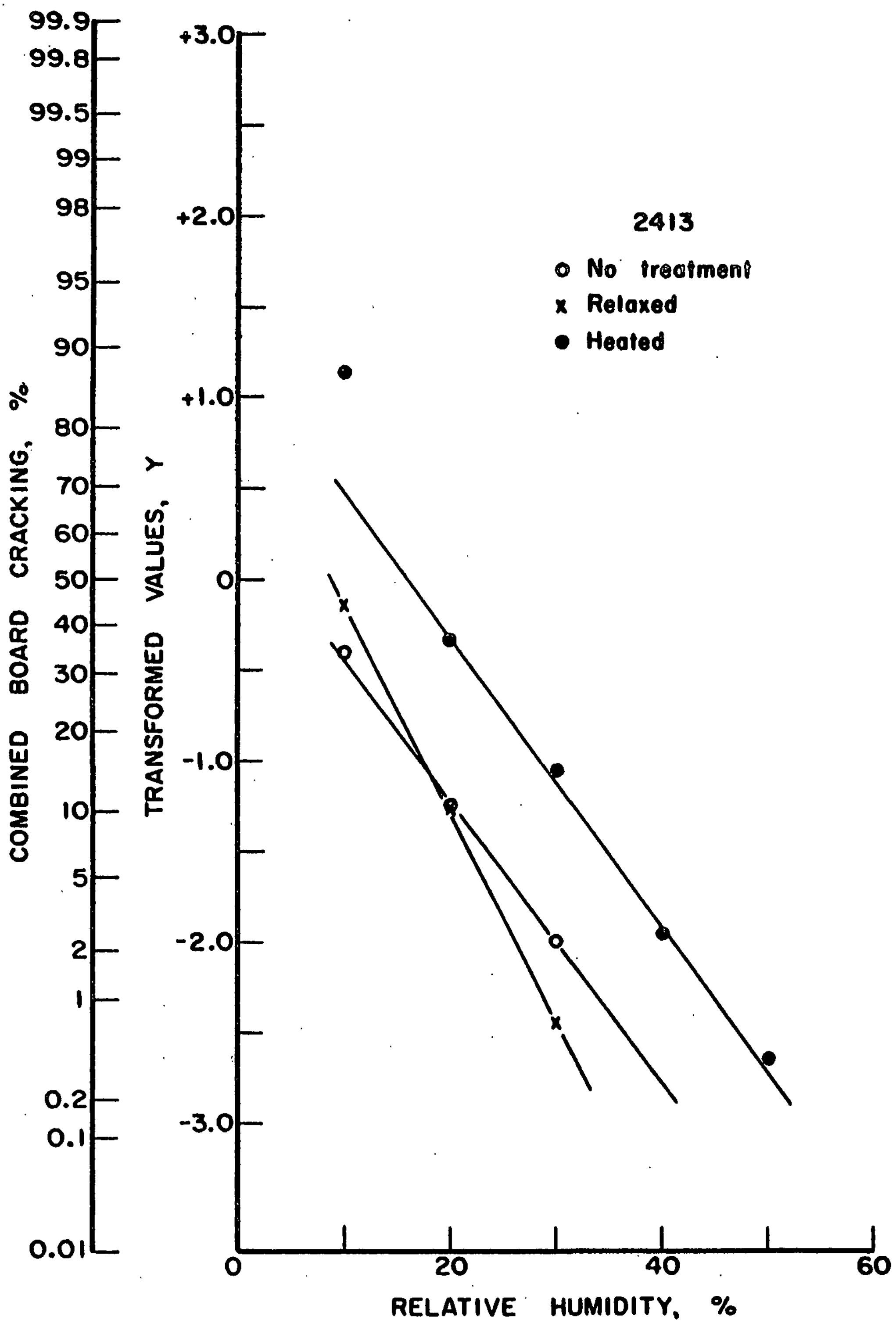

Fig. 5. Effect of Relative Humidity on Combined Board Cracking for Sample 2413

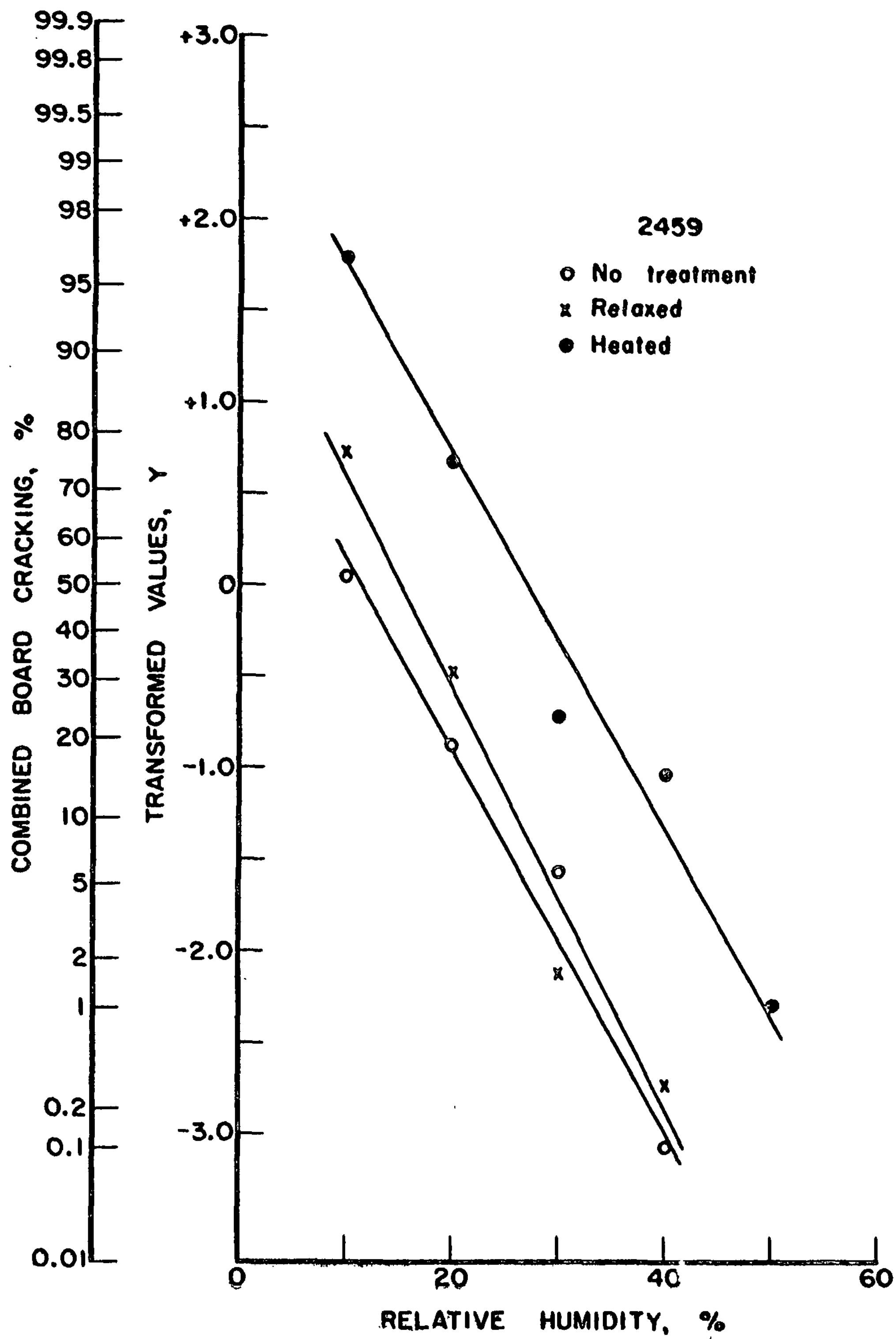

Fig. 6. Effect of Relative Humidity on Combined Board Cracking for Sample 2459

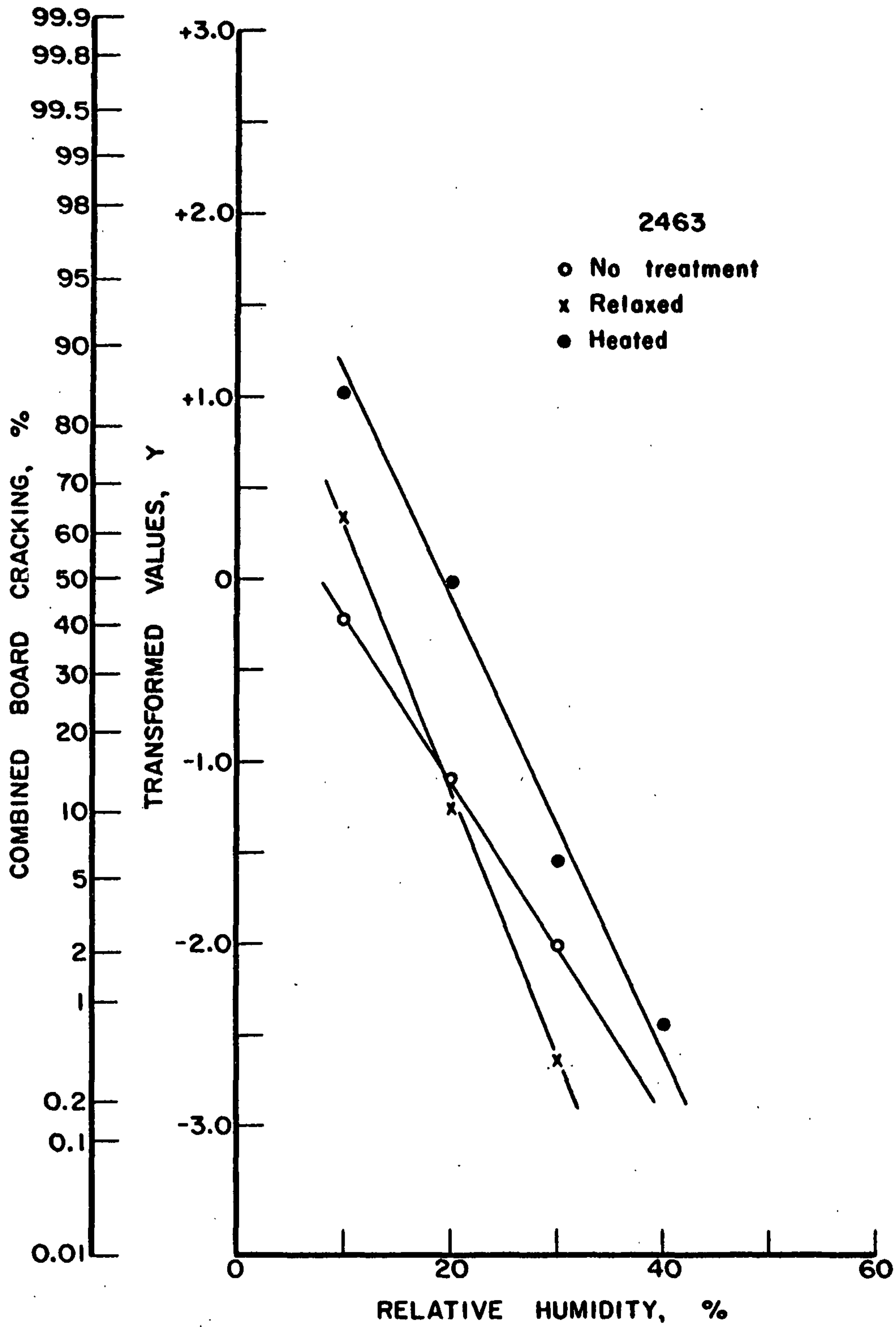

Fig. 7. Effect of Relative Humidity on Combined Board Cracking for Sample 2463

TABLE VII

RELATIONSHIP BETWEEN COMBINED BOARD CRACKING AND RELATIVE HUMIDITY

Sample No.	Data Subdivision	N	Intercept	Slope
2413	Control	3	0.39	-0.0800
	Relaxed	3	1.02	-0.1150
	Heated	5	1.80	-0.0923
2419	Control	4	0.38	-0.0871
	Relaxed	3	0.32	-0.0925
	Heated	5	0.55	-0.0712
2422	Control	5	1.80	-0.1005
	Relaxed	5	1.88	-0.1019
	Heated	5	2.40	-0.0926
2426	Control	4	0.17	-0.0830
	Relaxed	3	0.49	-0.1105
	Heated	5	1.19	-0.0792
2446	Control	5	1.07	-0.0822
	Relaxed	5	0.89	-0.0878
	Heated	5	2.51	-0.0838
2459	Control	4	1.16	-0.1012
	Relaxed	4	1.85	-0.1207
	Heated	5	2.64	-0.0988
2463	Control	3	0.68	-0.0895
	Relaxed	3	1.80	-0.1495
	Heated	4	2.25	-0.1201
2489	Control	5	1.71	-0.0933
	Relaxed	4	1.84	-0.1034
	Heated	5	2.18	-0.0820
Composite		102	1.11	-0.0804
Pooled[a]			1.27	-0.0863

[a]Obtained from an analysis of covariance - IBM program 6.0.032.

Two estimates for an "average" slope are provided in Table VII. The first is based on a regression equation obtained from the array of 102 data points and is equal to -0.0804. The second is a "pooled" value derived from the covariance analysis using IBM program 6.0.032 and may give a slightly better fit to the data. However, for most samples it will make little difference which line is used as is illustrated in Fig. 8.

The overall regression line for the 90-pound samples is also shown in Fig. 8. In general, the vertical distance between the regression lines for the 90 and 69-pound samples represents the average difference in degree of cracking for the two liner grades for the materials used in these studies. These differences would be as follows using the covariance estimate of the 69-pound regression line.

	Percent Cracking 69-pound	Percent Cracking 90-pound
10% R.H.	66	92
20% R.H.	32	69
30% R.H.	9.3	35
40% R.H.	1.5	10
50% R.H.	0.12	1.6

It also may be remarked that the difference in slope between the 90 and 69-pound grades was relatively small. For many purposes, the difference could be ignored and a graph such as in Fig. 9, Report 2, could be used to estimate cracking at various humidities if the cracking at one humidity level can be estimated, e.g., by making liner cracking tests at one humidity level.

LITERATURE CITED.

1. Grant, E. L. Statistical quality control. 1st ed. New York, McGraw-Hill Book Co., 1946.

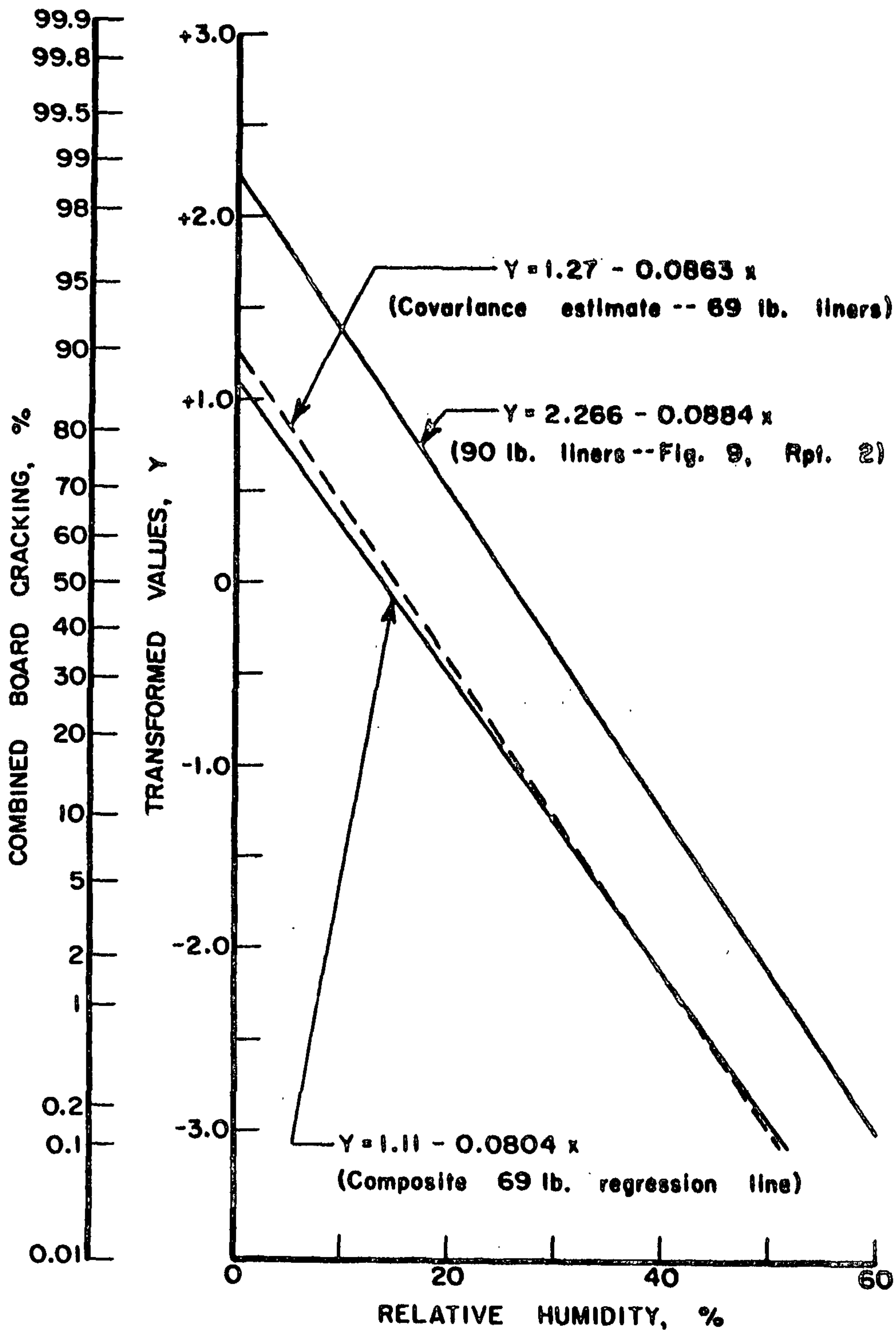

Fig. 8. Comparison of Regression Equations for Relationship Between Combined Board Cracking and Relative Humidity

APPENDIX I

COMBINED BOARD CRACKING PERCENTAGES TRANSFORMED TO NORMAL DEVIATE VALUE

Sample No.	Combined Board Cracking, transformed[a] 10% R.H.	20% R.H.	30% R.H.	40% R.H.	50% R.H.
			Untreated		
2413	-0.40	-1.24	-2.00	--	--
2419	-0.50	-1.32	-2.26	-3.09	--
2422	+0.83	-0.20	-1.18	-2.41	-3.09
2426	-0.73	-1.29	-2.51	-3.09	--
2446	+0.29	-0.32	-1.73	-2.46	-2.75
2459	+0.05	-0.88	-1.58	-3.09	--
2463	-0.22	-1.09	-2.01	--	--
2489	+0.81	-0.10	-1.23	-2.05	-2.88
		After High Humidity Relaxation			
2413	-0.15	-1.25	-2.45	--	--
2419	-0.51	-1.73	-2.36	--	--
2422	+0.84	0.0	-1.29	-2.33	-3.09
2426	-0.54	-1.87	-2.75	--	--
2446	+0.10	-0.69	-1.93	-3.09	-3.09
2459	+0.72	-0.49	-2.15	-2.75	--
2463	+0.34	-1.26	-2.65	--	--
2489	+0.95	-0.32	-1.51	-2.10	--
		After Drying at 125°C. for 36 Hours			
2413	+1.15	-0.33	-1.06	-1.96	-2.65
2419	-0.43	-0.61	-1.41	-2.41	-3.09
2422	+1.49	+0.57	-0.40	-1.37	-2.17
2426	+0.43	-0.18	-1.61	-1.94	-2.65
2446	+1.58	+0.95	-0.02	-0.77	-1.75
2459	+1.80	+0.66	-0.73	-1.04	-2.29
2463	+1.03	-0.02	-1.56	-2.46	--
2489	+2.07	+1.32	-0.35	-0.56	-1.09

[a]Transformed to normal deviate values using Table A, Appendix III of Reference (1).

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

EVALUATION OF THE IMPROVED LINERBOARD CRACKING TESTER USING 42-POUND LINERS

Project 1108-29

Report Four

A Preliminary Report

to

TECHNICAL COMMITTEE
FOURDRINIER KRAFT BOARD INSTITUTE, INC.

January 21, 1964

TABLE OF CONTENTS

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

EVALUATION OF THE IMPROVED LINERBOARD CRACKING TESTER USING 42-POUND LINERS

SUMMARY

Reports Two and Three discussed the correlation between combined board cracking and the liner cracking angle. The latter measurement was made on a tester developed at the Institute and involves folding the board over an anvil of known radius until cracking is observed. The past work utilized a number of lots of 69 and 90-pound liners and favorable correlations were obtained.

The above work has been extended to a number of 42-pound liner samples in this report with the following results:

1. Less favorable correlations were obtained with the 42-pound liner samples as compared to the previous work with 69 and 90-pound grades.

2. The overall regression equation of the probability type for the 42-pound liners was slightly displaced from the lines previously obtained for 69 and 90-pound liners. Therefore, for best predictions the separate regression lines for each grade should be used.

3. A covariance analysis indicated that the slopes of the regression lines for the three grades were not significantly different. Using a common slope, the following regression equations were obtained for the three grades:

Grade	Equation
42	$\underline{Y} = 8.42 - 0.149\underline{x}$
69	$\underline{Y} = 7.54 - 0.149\underline{x}$
90	$\underline{Y} = 7.90 - 0.149\underline{x}$

where $\underline{Y}$ = combined board cracking transformed to values of the normal deviate

$\underline{x}$ = liner cracking angle.

INTRODUCTION

Three previous reports have discussed the development of a tester for evaluating the score cracking potential of linerboard. Essentially, the test consists of folding the board over an anvil of known radius to induce tensile strains on the outside surface. The angle at which cracking is observed is measured.

In previous work, 90 and 69-pound liner samples were evaluated for their cracking angle and for their degree of cracking when used as the double-face liner of A-flute combined board. It was noted that:

a. the linerboard cracking tests appeared to be reasonably well related to the degree of combined board cracking;

b. useful relationships between the degree of combined board cracking and relative humidity were obtained; and

c. slightly different relationships of the probability type were required for the 90 and 69-pound grades.

This report discusses data obtained using 42-pound liners. The combined boards were made up using a 90-pound single-face liner and a test series in progress will employ a 42-pound single-face liner. A greater incidence of cracking would be expected using the heavier weight single-face liner and the greater degree of cracking may be helpful in evaluating the cracking relationships.

MATERIALS

The physical characteristics of the 42-pound liner samples used are tabulated in Table I.

TABLE I

PHYSICAL CHARACTERISTICS OF 42-POUND LINER SAMPLES

Sample No.	Basis Weight, lb./M ft.^{2}	Caliper, pt.	Tensile, lb./in. In	Tensile, lb./in. Cross	Stretch, % In	Stretch, % Cross
2410	42.8	13.4	79.9	34.3	1.6	4.3
2418	44.9	12.0	95.5	36.8	1.6	3.9
2421	42.7	12.6	86.7	37.2	1.8	3.8
2424	44.0	10.4	84.2	42.2	2.0	4.6
2436	43.0	12.1	88.6	37.0	2.1	3.7
2476	42.8	12.8	85.9	41.4	1.8	3.0

The above samples were fabricated into double-faced board and evaluated for folding at 10, 20, and 30% R.H. Higher humidities were not used because of the little cracking obtained at 30% R.H.

In addition, portions of each sample were subjected to a 36-hour exposure at 125°C. prior to double facing. They were then conditioned at 50% R.H. and 73°F. prior to scoring.

DOUBLE FACING, SCORING, AND FOLDING

Double-faced board was made by hand gluing sheets of the linerboard to a single-faced board corrugated on the Institute's experimental corrugator. With the exception that a 90-pound liner was used as the single-faced liner, the same conditions were used as specified in Report One.

Five sheets of board, with 3-11 inch long panel scores per sheet, were evaluated for cracking for each sample in each atmosphere. To increase crack visibility, a spray coating of flat black paint was used as described in the previous study.

Ten specimens of each linerboard sample were evaluated at each humidity level with the fold line at right angles to the machine direction. A spray coating of flat black paint was used to increase crack visibility and the rupture angle associated with the first appearances of a crack in the liner surface was measured.

DISCUSSION OF RESULTS

A tabulation of the combined board and linerboard cracking results obtained with 42-pound liners may be found in Table II. As in the previous studies the combined board and linerboard tests, in general, exhibit the expected trends with folding humidity and fabrication treatment.

In the previous reports, it was found that probability type equations appeared to have promise in the analysis of the relationship of combined board cracking to the liner cracking angle and relative humidity. With this in mind, the linerboard cracking was transformed to standard deviation units ($\underline{Y}$) as shown in Table II. A graph of the results in arithmetic probability coordinates is shown in Fig. 1 and the correlations are tabulated in Table III.

As may be noted, the correlations obtained were somewhat lower than were obtained with the 90 and 69-pound liner samples, possibly because of the difficulties in evaluating the lower degrees of cracking. Inspection of the data indicates that certain of the samples tended to exhibit consistent deviations from the other members of the group. For example, Sample No. 2424, a dense low caliper (10.4 pt.) sample, tended to exhibit considerably greater amounts of combined board cracking than would be expected from the liner cracking tests.

It may also be remarked that some difficulties were encountered in reproducing test results with the lighter weight liners. A check to determine if variations in the coating used for contrast are a possible cause for shifts in test readings is underway. In addition, a possible improvement in correlation through application of an initial strain to the liner cracking specimen is being investigated.

TABLE II

COMBINED BOARD AND LINERBOARD CRACKING RESULTS

Sample No.	Combined Board Cracking, % 10% R.H.	20% R.H.	30% R.H.	Combined Board Cracking Transformed to Normal Deviate Values 10% R.H.	20% R.H.	30% R.H.	Linerboard Cracking Angle, ° 10% R.H.	20% R.H.	30% R.H.
				Untreated					
2410	29.6	8.2	0.2	-0.54	-1.39	-2.88	63.8	68.9	72.4
2418	20.0	0.0	0.0	-0.84	--	--	68.2	72.8	74.4
2421	14.5	1.0	0.1	-1.06	-2.33	-3.09	63.1	66.6	67.4
2424	14.1	2.4	0.0	-1.08	-1.98	--	67.6	75.6	75.6
2436	33.2	2.5	0.2	-0.43	-1.96	-2.88	64.8	68.8	68.8
2476	2.4	1.2	0.0	-1.97	-2.26	--	66.8	70.6	70.2
				After drying at 125°C. for 36 hours					
2410	67.2	27.9	4.1	0.45	-0.59	-1.74	58.8	63.5	63.4
2418	34.6	21.7	5.9	-0.40	-0.78	-1.56	60.8	64.8	66.3
2421	20.0	5.5	1.1	-0.84	-1.60	-2.29	58.2	63.0	61.4
2424	75.8	37.2	4.0	0.70	-0.33	-1.75	60.8	66.2	67.8
2436	44.2	23.9	7.3	-0.15	-0.71	-1.45	58.6	62.6	64.9
2476	30.5	15.7	4.9	-0.51	-1.01	-1.66	58.7	62.6	64.4

Note: Linerboard cracking angle corresponding to initial observed crack.

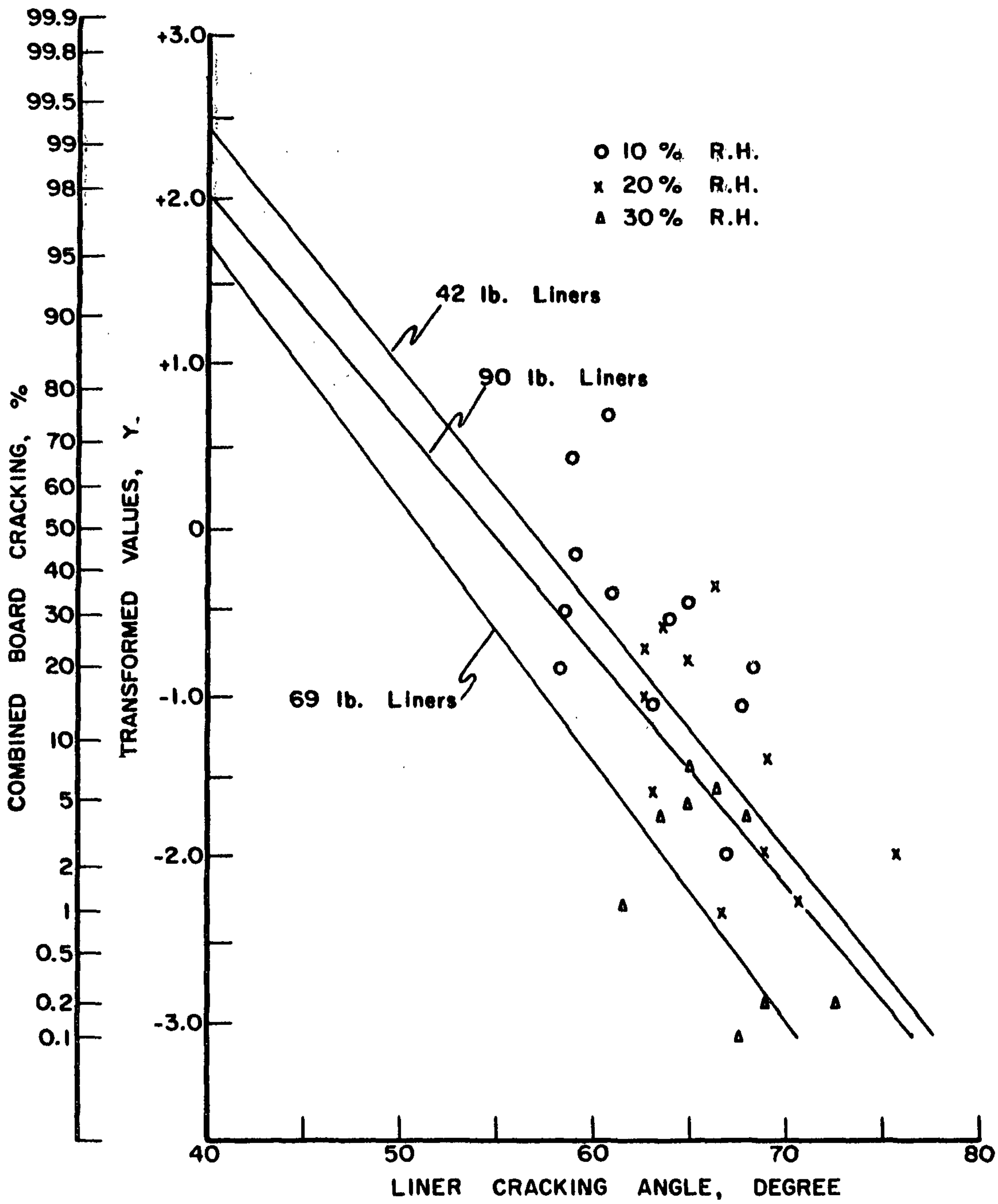

Figure 1. Relationship Between Combined Board Cracking and the Liner Cracking Angle for 42-Pound Liner Samples (Arithmetic Probability Coordinates)

TABLE III

CORRELATION OF COMBINED BOARD CRACKING AND THE LINERBOARD CRACKING TEST

Equation No.	Data Subdivision	N	Regression Equation[a]	Correlation Coefficient
			42-lb. Liners	
1	10% R.H.	12	$\underline{Y} = 6.45 - 0.112\underline{x}$	0.59
2	20% R.H.	11	$\underline{Y} = 5.73 - 0.106\underline{x}$	0.61
3	30% R.H.	9	$\underline{Y} = 4.98 - 0.107\underline{x}$	0.54
4	Overall	32	$\underline{Y} = 8.31 - 0.147\underline{x}$	0.65
			69-lb. Liners	
5	Overall	102	$\underline{Y} = 8.15 - 0.160\underline{x}$	0.93
			90-lb. Liners	
6	Overall	70	$\underline{Y} = 7.68 - 0.141\underline{x}$	0.94
			Combined Grades	
7	Overall	204	$\underline{Y} = 7.31 - 0.139\underline{x}$	0.88

[a] $\underline{Y}$ = combined board cracking transformed to standard deviation units.

$\underline{x}$ = liner cracking angle, °.

With the above in mind, it may be noted that the overall regression line for the 42-pound liner data was slightly displaced from the 90 and 69-pound regression lines. At this time it is not known whether the differences in regression line are due to experimental difficulties or to factors unaccounted for in the correlations.

An analysis of covariance using I.B.M. program 6.0.032 was used to determine if the slopes of the overall regression lines for the three grades were significantly different. The slopes were not statistically different—implying that regression lines of common slope could be used for the three liner grades. The covariance analysis gave the regression lines shown in Table IV.

TABLE IV

COVARIANCE REGRESSION LINES

Equation No.	Liner Grade, lb.	Regression Equation
8	42	$\underline{Y} = 8.42 - 0.149\underline{x}$
9	69	$\underline{Y} = 7.54 - 0.149\underline{x}$
10	90	$\underline{Y} = 8.18 - 0.149\underline{x}$
11	Combined	$\underline{Y} = 7.90 - 0.149\underline{x}$

These equations may be preferred over Equations (4), (5), and (6) because of the convenience of using a common slope. As may be noted in Fig. 2, the differences between the equations for the individual grades and the covariance equations of equal slope are relatively minor except near the data extremes.

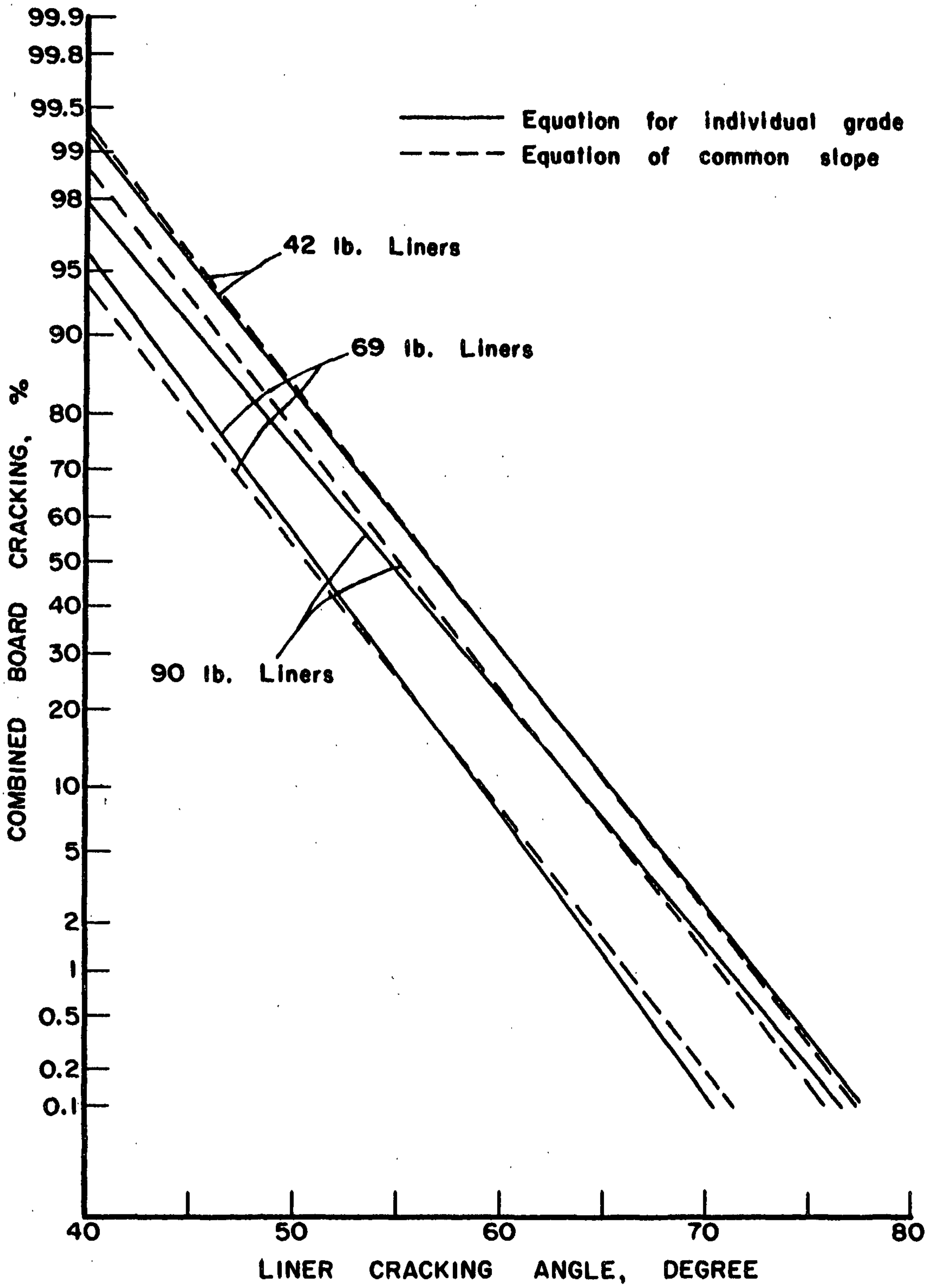

Figure 2. Comparison of Equal Slope Regression Lines with Regression Equation for Each Grade

The above equations indicate that an increase of one unit in the cracking angle will decrease Y by 0.149 units. To illustrate, the improvement in combined board cracking associated with a 0.15 unit decrease in Y, values are tabulated in Table V for various initial levels of Y. For example, if Y is changed from 0.0 to -0.15 the expected degree of combined board cracking will decrease from 50 to 44%, a change of 6%. Similarly, changing Y from -2.0 to -2.15 would change the percentage cracking from 2.28% to 1.50%. Thus, the absolute effectiveness of a one unit change in liner cracking angle is more apparent at higher levels of cracking.

TABLE V

EFFECT OF A ONE UNIT CHANGE IN THE LINER CRACKING ANGLE ON COMBINED BOARD CRACKING

Normal Deviate (Y) Original Level	New Level	Combined Board Cracking, % Original Level	New Level	Change
0.0	-0.15	50.0	44.0	6.0
-1.0	-1.15	15.9	12.5	3.4
-1.5	-1.65	6.7	5.0	1.7
-2.0	-2.15	2.28	1.58	0.73
-2.5	-2.65	0.62	0.40	0.22

Because the evaluations were only possible at the three lower humidities, a detailed analysis of the relationship between combined board cracking and relative humidity could not be carried out for each sample. An overall regression equation was obtained, however, with a slope equal to -0.0795. This value was about the same as that obtained with 69-pound liners, -0.0804, and it is assumed that the regression equation for the pooled 69-pound liner data in Table VII of Report Three would be suitable for 42-pound liners.

THE INSTITUTE OF PAPER CHEMISTRY

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EVALUATION OF THE INFLUENCE OF THE SINGLE-FACE LINER AND INITIAL STRAIN ON COMBINED BOARD AND LINERBOARD CRACKING

Project 1108-29

Report Five

A Preliminary Report

to

TECHNICAL COMMITTEE
FOURDRINIER KRAFT BOARD INSTITUTE, INC.

March 9, 1964

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

EVALUATION OF THE INFLUENCE OF THE SINGLE-FACE LINER AND INITIAL STRAIN ON COMBINED BOARD AND LINERBOARD CRACKING

SUMMARY

Previous work has established that the linerboard cracking tester developed at the Institute is reasonably well related to combined board cracking. Best results were obtained for the heavier grades. Less favorable results were obtained, however, with 42-lb. liners. In an effort to improve the relationships for the lighter weight liners a number of avenues of approach were explored.

The results may be summarized as follows:

1. Application of various levels of initial strain in the linerboard cracking tester lowered the final cracking angle as would be expected. However, little or no improvements in the 42-lb. grade correlations were obtained. It appears, therefore, that the tester is more effective in the heavier liner weights.

2. Changing the single-face liner from a 90 to 42-lb. grade markedly lowered the degree of combined board cracking when 42-lb. liners were used as double facers. No improvements in correlation were obtained using the results based on the lighter-weight single-face liner.

In view of the above it is proposed that work in the immediate future continue along two avenues of approach. They are

1. to investigate the fiber and sheet characteristics which influence the foldability of heavyweight linerboard,

and 2. to continue investigations into the variables of the tester and the folding operation with the objective of improving cracking predictions. Specifically, it is suggested that attention be directed towards

a) Determining if improvements in clamping would increase reproducibility.

b) Studying the effect of anvil radius on cracking correlation.

c) Determining if force or optical measurements could be used to detect cracking as a function of angle.

INTRODUCTION

Four previous reports have discussed the development of a tester for evaluating the score cracking potential of linerboard. Essentially, the test consists of folding the board over an anvil of known radius to induce tensile strains on the outside surface. The angle at which cracking is observed is measured. A photograph of the apparatus is shown in Fig. 1.

In previous work, 42, 69, and 90-lb. liner samples were evaluated for their cracking angle and for their degree of cracking when used as the double-face liner of A-flute combined board. A 90-lb. single-face liner was used for all samples. In general, it was noted that

(a) The linerboard cracking tests appeared to be reasonably well related to the degree of combined board cracking in the 69 and 90-lb. grades.

(b) Less favorable relationships were obtained with the 42-lb. liner samples.

(c) A covariance analyses indicated that the slopes of the regression lines for the three grades were not significantly different. Using a common slope, the following regression equations were obtained:

Grade	Equation
42	$\underline{Y} = 8.42 - 0.149\underline{x}$
69	$\underline{Y} = 7.54 - 0.149\underline{x}$
90	$\underline{Y} = 7.90 - 0.149\underline{x}$

Since the last report, development work on the tester involved the following:

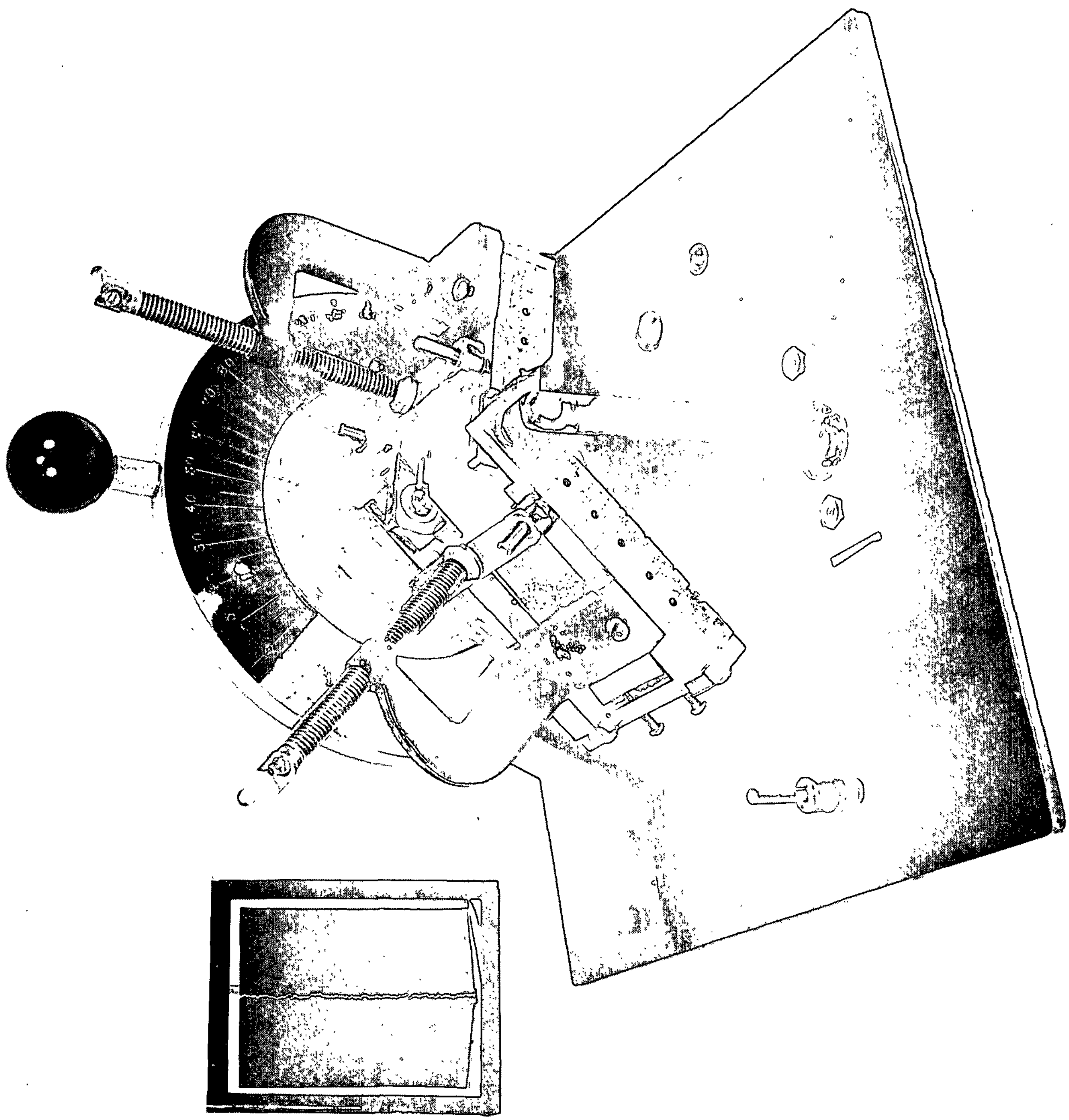


Figure 1. Modified Linerboard Foldability Tester

1. Preparation and cracking evaluation of combined board made with a 42-lb. single-face liner and the six 42-lb. double-face liner samples used in past work.

2. A limited investigation of the influence of paint thickness (used to improve detection of cracking) on linerboard cracking results.

3. An evaluation of the effect of prestrain on the linerboard cracking angle.

4. Cracking angle evaluation of the 42-lb. liner samples using two levels of prestrain.

In past operation of the linerboard cracking tester, the top surfaces of the two anvils are in the same plane when the specimen is clamped (see Fig. 2). By clamping the specimen with the rotating clamp making an initial angle with the fixed clamp as shown in Fig. 2, the equivalent of an initial strain (termed prestrain) may be applied to the specimen. Thus, the initial specimen length is shorter in Fig. 2B than 2A and it will be stretched as the rotating clamp is moved toward the usual starting position. The amount of prestrain will depend on the initial angle. The following estimates were made:

Prestrain Angle, degrees	Per Cent Strain
- 5	0.1
-10	0.4
-15	0.9

Thus, the amount of prestrain increases rapidly as the initial angle is increased. In general, prestrain will have the effect of lowering the final cracking angle because the prestrain is added to the strains developed during bending of the specimen about the anvils.

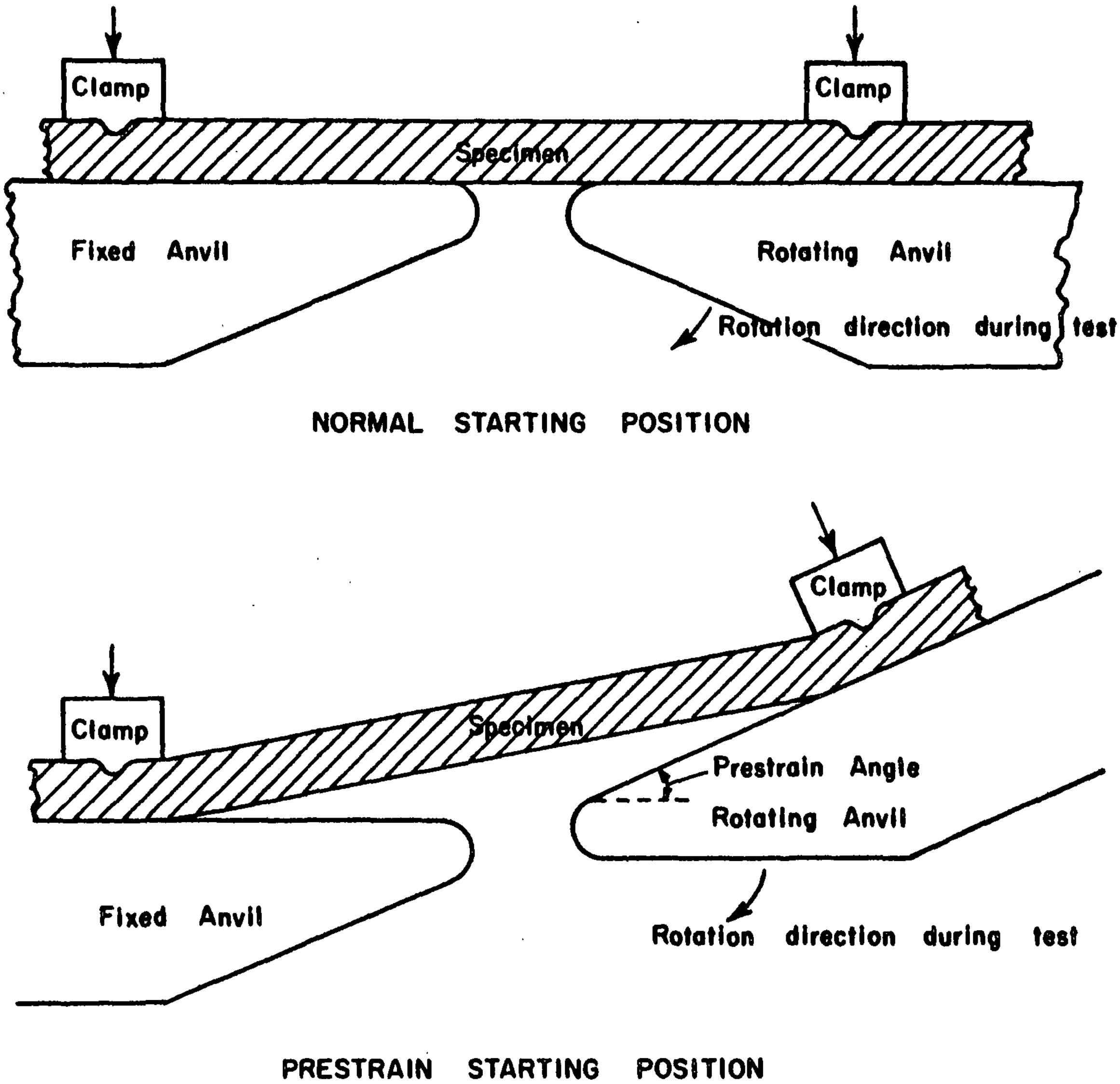


Figure 2. Schematic Illustration of Procedure Used in Applying the Equivalent of an Initial Strain. Top – A, Bottom – B.

MATERIALS

The 42-lb. liner samples, described in Report Four, were combined for the purpose of this report with an A-flute single-faced board fabricated with a 42-lb. single-face liner. (Note: In Report Four a 90-lb. single-face liner was used.) The physical characteristics of the samples used as double-face liners are tabulated in Table I.

TABLE I

PHYSICAL CHARACTERISTICS OF 42-POUND LINER SAMPLES

Sample No.	Basis Weight, lb./M ft.^{2}	Caliper, pt.	Tensile, lb./in. In	Tensile, lb./in. Cross	Stretch, % In	Stretch, % Cross
2410	42.8	13.4	79.9	34.3	1.6	4.3
2418	44.9	12.0	95.5	36.8	1.6	3.9
2421	42.7	12.6	86.7	37.2	1.8	3.8
2424	44.0	10.4	84.2	42.2	2.0	4.6
2436	43.0	12.1	88.6	37.0	2.1	3.7
2476	42.8	12.8	85.9	41.4	1.8	3.0

The above samples were fabricated into double-faced board and evaluated for folding at 10, 20, and 30% R.H. Higher humidities were not used because of the limited amount of cracking obtained at 30% R.H.

In addition, portions of each sample were subjected to a 36-hour exposure at 125°C. prior to double facing. They were then conditioned at 50% R.H. and 73°F. prior to scoring.

Double facing scoring and folding: The same procedures described in past work were used in preparing and evaluating the liner and combined board.

DISCUSSION OF RESULTS

DEPENDENCE OF COMBINED BOARD CRACKING ON SINGLE-FACE LINER

When combined board is folded, McKee and Altmann (1) have shown that a rapid increase in torque occurs at an angle of about 135°. At this stage of the fold, the inside liner has been folded back on itself forming an anvil about which the double-face liner is being drawn or strained [see the photograph in Fig. 3 which is similar to those shown in Reference (1)]. Thus, an impasse is encountered in that the single-face liner cannot be displaced outwardly and the double-face liner is restrained from its inward displacement by the compression anvil formed by the single-face liner. As a result, the torque rapidly increases until the single-face liner is distorted or displaced sufficiently to permit consummation of the fold. If the strains induced in the double-face liner during this process become too great, then cracking of the double-face liner will occur.

In view of the above, it may be anticipated that the degree of combined board cracking will be dependent, in part, on the stiffness of the single-face liner and medium. The results in Table II illustrate the differences in cracking obtained on combined board samples fabricated with 42 and 90-lb. single-face liners. It may be noted that:

(a) Considerably smaller amounts of cracking were obtained with the 42-lb. single-face liner.

(b) With the 42-lb. single-face liner, none of the 42-lb. untreated double-face liner samples exhibited any serious cracking at either 20 or 30% R.H. Even at 10% R.H., only slight amounts were obtained.

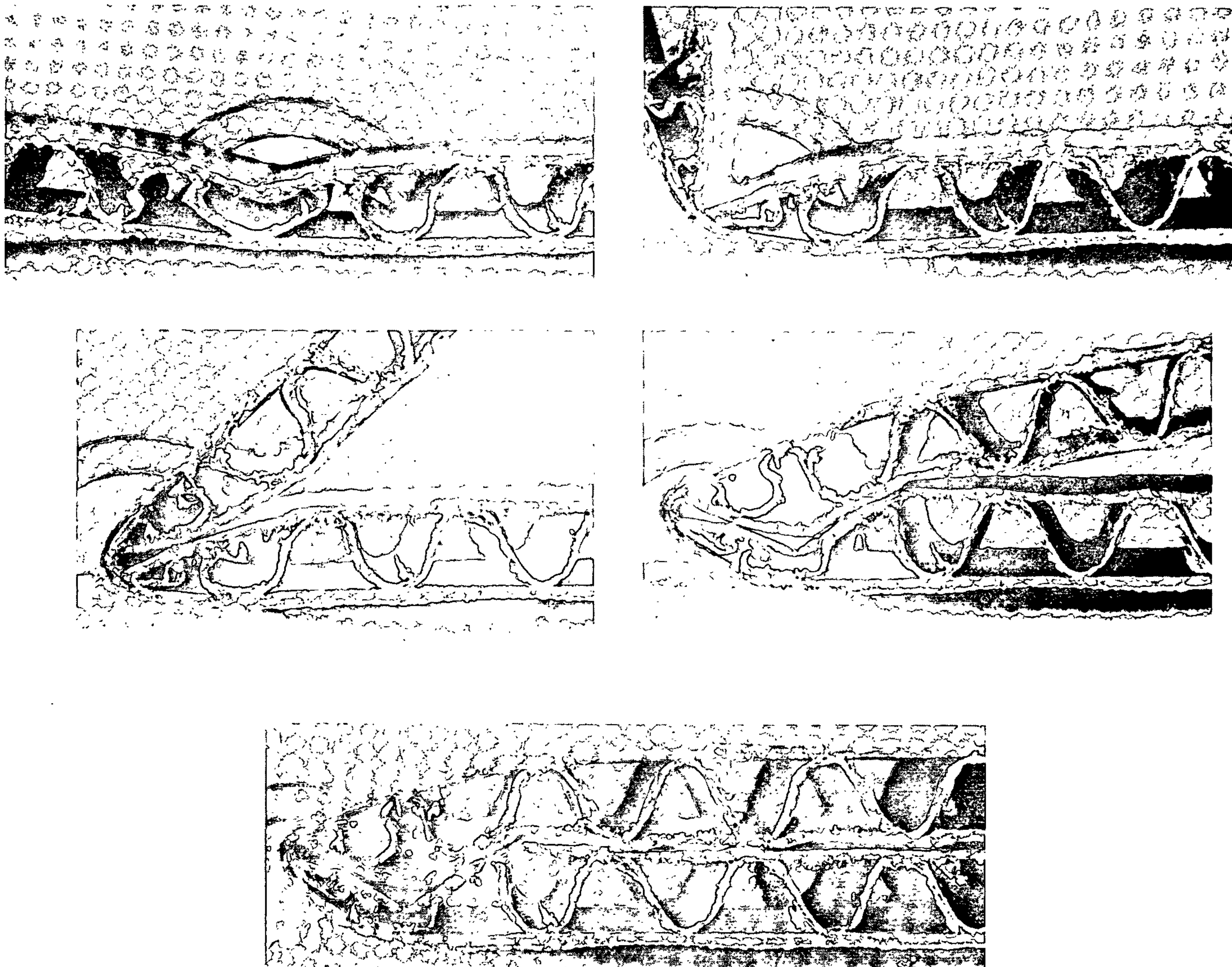
42 lb.

-1- 7° Fold

-2- 72° Fold

-3- 133° Fold

-4- 164° Fold



180° Fold

-5-

Figure 3. Stages on Combined Board Folding

TABLE II

EFFECT OF SINGLE FACE LINER WEIGHT ON CRACKING OF COMBINED BOARD MADE WITH 42-LB. DOUBLE FACE LINERS

Sample No.	Combined Board Cracking, %					
	10% R.H.		20% R.H.		30% R.H.	
	90 lb. S.F. Liner[a]	42 lb. S.F. Liner	90 lb. S.F. Liner[a]	42 lb. S.F. Liner	90 lb. S.F. Liner[a]	42 lb. S.F. Liner
Untreated						
2410	29.6	1.6	8.2	0.0	0.2	0.0
2418	20.0	0.7	0.0	0.0	0.0	0.0
2421	14.5	1.5	1.0	0.0	0.1	0.0
2424	14.1	10.7	2.4	0.0	0.0	0.0
2436	33.2	9.6	2.5	0.0	0.2	0.0
2476	2.4	0.1	1.2	0.0	0.0	0.0
Composite	19.0	4.0	2.6	0.0	0.1	0.0
After Drying at 125°C. for 36 hours						
2410	67.2	15.7	27.9	0.9	4.1	0.6
2418	34.6	16.7	21.7	1.3	5.9	0.8
2421	20.0	3.4	5.5	0.5	1.1	0.1
2424	75.8	44.4	37.2	6.6	4.0	1.2
2436	44.2	46.7	23.9	7.7	7.3	5.2
2476	30.5	18.9	15.7	4.5	4.9	0.1
Composite	45.4	24.3	22.0	3.6	4.6	1.3

[a] Taken from Report 4, January 21, 1964.

(c) Thus, the stiffer and heavier the single-face liner, the more frequently will cracking problems be encountered.

EFFECT OF PAINT THICKNESS ON LINER CRACKING RESULTS

Early in the development of the tester, it was thought desirable to apply a spray coating of flat black paint to the board surface to facilitate detection of cracking. Similar techniques have been used by investigators in other fields.

While such coatings should not affect the properties of the board it was thought possible that coating thickness variations might be responsible for some of the problems encountered in evaluating the lighter liners. To investigate this possibility, two 69 and one 42-lb. liner sample were evaluated for cracking after giving the board a number of spray passes. The results are shown in Table III and suggest that

(a) Unless excessive quantities are applied, the 69-lb. liner results are not affected.

(b) The 42-lb. liner results were possibly more sensitive to the coating thickness.

While the results do not show any great dependence on coating variations, reasonable care in application is recommended.

EFFECT OF PRESTRAIN ON LINER CRACKING

As discussed previously, a simple modification of the linerboard cracking tester was made to permit imposing the equivalent of an initial tension strain in the specimen. This has the effect of lowering the angle at which cracking will be observed and would permit evaluation of materials which do not crack within the rotational limits of the present tester. It was also thought possible that improvements in correlation of the 42-lb. liner cracking results might result.

TABLE III

EFFECT OF VARIATIONS IN COATING ON LINER CRACKING RESULTS

No. of Spray Passes	Liner Cracking Angle, degrees		
	42-lb. Liner	69-lb. Liner Sample 1	69-lb. Liner Sample 2
1	74.8	53.5	48.5
2	73.3	52.6	48.5
3	77.2	52.2	48.7
4	80.0	54.0	52.3

To illustrate the effect of applying an initial strain, three 42 and two 69-lb. liner samples were evaluated using initial starting angles of -5 and -10°. The results are shown in Table IV and indicate that

a. On the average, the change in cracking angle was nearly equal to the prestrain angle.

b. The 69-lb. liner samples appeared to exhibit somewhat smaller changes in cracking angles than the 42-lb. liner samples. This possibly suggests that bending strains are more important to 69-lb. liner cracking than to 42-lb. liner cracking due to the differences in caliper.

CORRELATION OF 42-LB. LINER RESULTS

The 42-lb. liner samples mentioned previously were evaluated for cracking angle using the 5 and 10 degree levels of prestrain. The results are

TABLE IV

EFFECT OF PRESTRAIN ON THE LINER CRACKING ANGLE

Sample No.	Liner Weight	Liner Cracking Angle, degree — Degree of Prestrain, Control	5°	Diff.	10°	Diff.
				10% R.H.		
2410	42	67.9	59.6	-8.3	54.8	-13.1
2418	42	68.9	62.4	-6.5	56.3	-12.6
2421	42	65.7	59.8	-5.9	55.7	-10.0
2489	69	46.0	42.8	-3.2	38.8	-7.2
1000	69	50.7	46.5	-4.2	41.5	-9.2
Composite		59.8	54.2	-5.6	49.4	-10.4
				20% R.H.		
2410	42	74.3	69.3	-5.0	61.4	-12.9
2418	42	75.6	71.5	-4.1	62.2	-13.4
2421	42	70.0	65.7	-4.3	62.6	-7.4
2489	69	52.4	48.4	-4.0	43.3	-9.1
1000	69	54.7	52.0	-2.7	47.6	-7.1
Composite		65.4	61.4	-4.0	55.4	-10.0
				30% R.H.		
2410	42	75.8	69.2	-6.6	64.7	-11.1
2418	42	77.1	70.6	-6.5	62.8	-14.3
2421	42	70.4	62.6	-7.8	58.6	-11.8
2489	69	53.8	48.8	-5.0	45.1	-8.7
1000	69	56.8	52.4	-4.4	48.3	-8.5
Composite		66.8	60.7	-6.1	55.9	-10.9

shown in Table V and the correlations with combined board cracking are summarized in Table VI. In general, slight improvements in correlation were obtained by using the 5 or 10 degree levels of prestrain on the overall data. Inspection of Fig. 4 where the 10° prestrain results are plotted indicates there is considerable scatter about the regression lines.

Therefore, it appears at present that the liner cracking angle test is more effective in the heavier liner weights.

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1. McKee, R. C., and Altmann, F. J. Comparative evaluation of panel or body creasing wheel contours. Tappi 39, no. 7:503-14(July, 1956).

THE INSTITUTE OF PAPER CHEMISTRY

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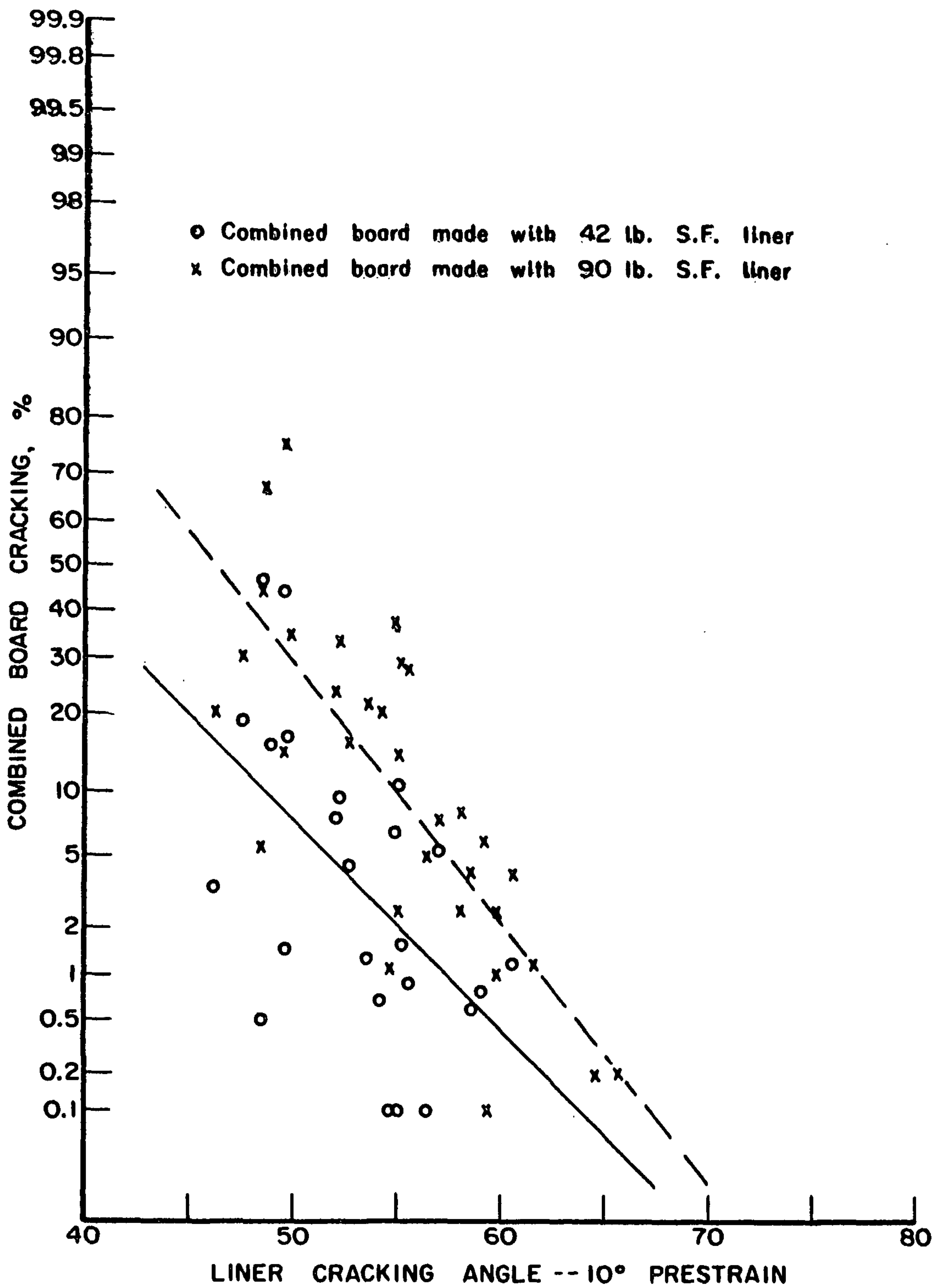

Figure 4. Relationship Between Combined Board Cracking and the Liner Cracking Angle

TABLE VI

CORRELATION OF 42-LB. CRACKING RESULTS

		Combined Board Samples Made With 90-Lb. Single Face Liner[a]				Combined Board Samples Made With 42-Lb. Single Face Liner[a]			
Equation No.	Degree of Prestrain Used In Testing Liner	N	Regression Constants Intercept	Regression Constants Slope	Correlation Coefficient	N	Regression Constants Intercept	Regression Constants Slope	Correlation Coefficient
				10% R.H. data					
1	0	12[b]	6.45	-0.112	-0.59	12	8.13	-0.153	-0.62
2	5	12	4.45	-0.084	-0.36	12	7.78	-0.155	-0.51
3	10	12	4.75	-0.104	-0.47	12	6.56	-0.157	-0.55
				Over-all Data					
7	0	32[b]	8.31	-0.147	-0.65	24	7.08	-0.141	-0.50
8	5	32	7.33	-0.136	-0.71	24	5.33	-0.116	-0.54
9	10	32	6.78	-0.147	-0.77	24	4.44	-0.118	-0.54

[a] Combined board cracking results transferred to standard deviation units.
[b] Results taken from Report Four.

TABLE V

COMBINED BOARD AND LINER CRACKING RESULTS

Sample No.	Combined Board Cracking, %: Made With 90-Lb. S.F. Liner, 10% R.H.	20% R.H.	30% R.H.	Made with 42-Lb. S.F. Liner, 10% R.H.	20% R.H.	30% R.H.	Liner Cracking Angle: 5 Degree Prestrain, 10% R.H.	20% R.H.	30% R.H.	10 Degree Prestrain, 10% R.H.	20% R.H.	30% R.H.
Untreated												
2410	29.6	8.2	0.2	1.6	0.0	0.0	59.4	66.1	74.0	55.2	58.1	65.5
2418	20.0	0.0	0.0	0.7	0.0	0.0	65.0	68.9	74.4	54.2	59.9	65.4
2421	14.5	1.0	0.1	1.5	0.0	0.0	58.8	64.1	68.7	49.6	59.8	59.3
2424	14.1	2.4	0.0	10.7	0.0	0.0	62.0	71.1	77.6	55.0	59.8	63.8
2436	33.2	2.5	0.2	9.6	0.0	0.0	59.0	65.4	73.0	52.2	58.0	64.5
2476	2.4	1.2	0.0	0.1	0.0	0.0	63.0	67.5	73.8	55.0	61.5	64.7
Composite	19.0	2.6	0.1	4.0	0.0	0.0	61.2	67.2	73.6	53.5	59.5	63.9
After Drying at 125°C. for 36 hours												
2410	67.2	27.9	4.1	15.7	0.9	0.6	58.0	63.3	67.0	48.8	55.5	58.5
2418	34.6	21.7	5.9	16.7	1.3	0.8	60.0	62.9	71.7	49.8	53.5	59.1
2421	20.0	5.5	1.1	3.4	0.5	0.1	55.6	59.0	62.2	46.2	48.4	54.7
2424	75.8	37.2	4.0	44.4	6.6	1.2	60.4	64.9	65.3	49.6	54.8	60.6
2436	44.2	23.9	7.3	46.7	7.7	5.2	55.8	61.7	64.6	48.4	51.9	56.9
2476	30.5	15.7	4.9	18.9	4.5	0.1	55.2	60.5	66.8	47.6	52.7	56.3
Composite	45.4	22.0	4.6	24.3	3.6	1.3	57.5	62.0	66.3	48.4	52.8	57.7

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Appleton, Wisconsin

LINERBOARD CRACKING: DEVELOPMENT OF IMPROVED COATING PROCEDURES AND THE EFFECTS OF SINGLE-FACE LINER WEIGHT AND MEDIUM STIFFNESS ON COMBINED BOARD CRACKING

Project 1108-29

Report Seven

A Preliminary Report

to

FOURDRINIER KRAFT BOARD INSTITUTE, INC.
TECHNICAL DIVISION

February 2, 1965

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

LINERBOARD CRACKING: DEVELOPMENT OF IMPROVED COATING PROCEDURES AND THE EFFECTS OF SINGLE-FACE LINER WEIGHT AND MEDIUM STIFFNESS ON COMBINED BOARD CRACKING

SUMMARY

As noted in past reports, the linerboard cracking tester has correlated reasonably well with combined board cracking. In the past work a coating of flat black paint was applied to both combined board and linerboard test areas in order to facilitate detection and measurement of cracking. It was felt that the paint would not materially alter the physical characteristics of the board surface. As one phase of the current work the effect of the coating was re-evaluated by measuring the change in tensile characteristics of lightweight kraft paper before and after coating. In general, the results indicated that:

1. The tensile and stretch of the sheet were increased if the coating of black paint or ink were allowed to dry.

2. Little or no change in tensile or stretch occurred in the first two to four hours after application.

3. A change in coating procedure would be desirable. Currently, a modified procedure involving the printing of a thin ink film on the test surface is being investigated.

As an alternative to the application of a semiliquid coating, it appeared possible to use a dry coating of carbon black. This appeared to avoid any altering of the physical characteristics of the sheet. A trial of the above procedure indicated, however, that poorer correlations with combined board cracking were obtained and the approach was abandoned.

In developing the correlations of the linerboard tester with combined board cracking it was desirable to fabricate the combined boards holding the single-face liner and medium constant. It was recognized, however, that in the field the degree of cracking would be dependent on the combined board composition. To illustrate this, combined boards were fabricated with 42, 69, and 90 lb. single-face liners using mediums varying in flat crush from about 28 to 55 p.s.i. The combined boards were scored and folded and the degree of cracking was measured with the following results:

1. Increasing the single-face liner weight increased combined board cracking as would be expected because the heavier weight liner forms a stiffer anvil.

2. The higher amounts of cracking tended to be obtained with the lower flat crush mediums — where smaller radii of curvature seemed to be obtained. These results were somewhat unexpected and should be viewed with caution.

As a final phase of the work since the last report, a number of samples of 90-lb. laminated linerboard made with low and high hardwood contents were forwarded to the Institute by the Union Bag-Camp Paper Corp. The linerboard cracking tester results have been made available to the group with the kind permission of the Union Bag-Camp Paper Corp. The results indicated that considerably greater cracking would be expected from the samples made with high hardwood contents.

INTRODUCTION

As mentioned in Report Six current work is oriented toward two broad objectives, namely (1) determining ways of modifying board to reduce cracking and (2) improve the linerboard tester developed at the Institute. With regard to the first objective, it is planned to study such variables as the effect of additives, fiber furnish, etc., using the Institute's web former to produce the experimental boards. For this phase of the work a secondary slice will be installed on the machine to more closely simulate the structure of commercial boards. This is now in progress.

In the meantime, a number of studies have been initiated which are directed toward the second goal. These are:

1. An investigation into the effect of anvil diameter on the correlation of linerboard cracking tester results with combined cracking.

2. A limited investigation of the possible effect of the black paint coating on cracking evaluation.

3. A study of the effect of single-face liner weight and medium stiffness (flat crush) on combined board cracking.

4. A limited investigation of the effect of hardwood content on cracking.

In the first study, it is planned to construct anvils having radii of 0.010 (present size), .025, .050, and .075 inch. It seems possible that the larger radii might improve the relationship between linerboard cracking tester results and actual combined board cracking because radius measurements of the double-face liner in the form of folded combined board indicates that the "folded radii" are greater than .010 inch. The anvils are now being constructed.

The present report discusses the results obtained in Studies 2 and 3 above.

PROCEDURES

A. Effect of single-face liner weight and medium stiffness (flat crush) on combined board cracking.

Combined boards were fabricated in the material combinations shown in Table I and the physical characteristics of the materials used are shown in Table II. The single facing was carried out on the Institute's experimental corrugator using starch as the adhesive. The double backing was carried out by hand as in past work.

After fabrication, the combined boards were panel scored using a V-male vs. flat female score profile. The scoring clearance was set equal to the sum of the liner and medium calipers plus 0.005 inch.

The scored boards were spray coated using Rust Oleum flat black paint No. 412 by holding the container about 12 inches from the board surface and moving it slowly along the length of the score. The paint was allowed to dry for at least 24 hours at less than 35% R.H. and conditioned at least 48 hours at 50% R.H. prior to conditioning the board in the test atmosphere. Folding and measurements of crack length were carried out at 10, 20, 30, and 50% R.H.

B. Effect of coating on physical characteristics of kraft paper.

Limited past work had indicated that cracking evaluations were not materially affected by the amount of black paint applied — at least within reasonable limits. As an alternative approach it was decided to apply the paint to a lightweight kraft paper to determine if the paint affected the sheet

TABLE I

MATERIAL COMBINATIONS

No.	Liner Weight, lb./M ft.^{2} D.F.	S.F.	Medium Flat Crush, p.s.i.
1	69	42	28-30[a]
2	69	69	28-30[a]
3	69	90	28-30[a]
4	69	42	30-31
5	69	69	30-31
6	69	90	30-31
7	69	42	38-39
8	69	69	38-39
9	69	90	38-39
10	69	42	50-60[b]
11	69	69	50-60[b]
12	69	90	50-60[b]
13	90	42	28-30[a]
14	90	69	28-30[a]
15	90	90	28-30[a]
16	90	42	30-31
17	90	69	30-31
18	90	90	30-31
19	90	42	38-39
20	90	69	38-39
21	90	90	38-39
22	90	42	50-60[b]
23	90	69	50-60[b]
24	90	90	50-60[b]

[a] Originally intended to be 25-26 p.s.i.
[b] A resin impregnated medium sample.

properties. A lightweight sheet was needed to enhance any effect — therefore, a 50-lb. flat kraft sack paper was used. For the initial trials the following coatings were applied.

1. Uncoated
2. One spray pass with Rust Oleum No. 412
3. Two spray passes with Rust Oleum No. 412
4. Four spray passes with Rust Oleum No. 412
5. One No. 4 Meyer rod application of a flat red corrugating ink. No. 59NK2463

TABLE II

PHYSICAL CHARACTERISTICS OF LINERS AND MEDIUM

No.	Weight, lb./M ft.^{2}	Caliper, pt.	M.D. Tensile, lb./in.	M.D. Stretch, %	M.D. Modified Ring Crush, lb./in.	Concora Flat Crush, p.s.i.	Cracking Angle, °[a]
			Double-Face Liners				
4433	68.7	21.7	127.8	1.2	31.5	--	50.5
2495	90.3	25.9	144.6	1.9	43.0	--	47.5
			Single-Face Liners				
2516	42.8	12.5	90.8	1.6	23.7	--	--
4433	68.7	21.7	127.8	1.2	31.5	--	--
2501	89.9	26.9	130.8	1.7	41.3	--	--
			Corrugating Medium				
4641	27.7	8.4	--	--	16.3	29.2	--
9035	25.3	10.0	--	--	17.6	34.0	--
9051	26.8	10.3	--	--	18.7	41.8	--
4682	29.5	9.9	--	--	24.2	58.6	--

[a]Determined at 30% R.H.

The above sheets were coated and then preconditioned for at least 24 hours at less than 35% R.H., 73°F. They were then conditioned for at least 48 hours at 50% R.H. and 73°F. prior to test. Tensile, stretch, Taber stiffness and porosity tests were made.

A second series of comparisons were then made to evaluate the effect of drying time on the tensile and stretch characteristics. The following drying times were investigated.

1. Rust Oleum No. 412: 5, 60, 120, 240, and 1440 minutes
2. Black Proving Ink No. 319B: 5 and 60 minutes

C. Use of dry carbon black as a crack detector.

After initial results indicated that dry carbon black (Witco No. 50) could be used to coat the area to be evaluated in a reasonably satisfactory way, it was thought this would be an ideal solution, i.e., the dry carbon particles could have no possible effect on the strength characteristics of the outer fibrous layers. To determine if linerboard cracking tester results obtained using carbon black to enhance crack visibility would correlate with the combined board cracking results previously obtained using black paint, a number of 90 and 69-lb. liner were evaluated for cracking at 10 and 30% R.H. The samples were selected from those previously reported on in Reports Two and Three. Ten tests were made on each material in each atmosphere.

DISCUSSION OF RESULTS

A. Effect of single-face liner weight and medium stiffness on combined board cracking.

In the earlier studies, major attention was focussed on the development of a linerboard tester which would correlate with combined board cracking. To establish the degree of correlation it was necessary to vary only the double-face liner in fabricating the combined boards. Thus, for a given grade weight of liner, the single-face liner and medium were held constant. It was recognized, however, that the degree of combined board cracking would be dependent to some extent on the characteristics of the single-face liner and medium. To illustrate this dependence, a limited study was conducted in which 69 and 90-lb. double-face liners were combined with 42, 69, and 90-lb. single-face liners using four mediums ranging in flat crush from 28 to about 55 p.s.i.

The results obtained are tabulated in Table III and the 10% R.H. results are graphically illustrated in Fig. 1 and 2. Referring to the table or Fig. 1, it may be noted that the degree of cracking increased with single-face liner weight as would be expected. The most substantial increases were obtained in going from the 69 to 90-lb. single-face liner while only small differences in cracking tended to be obtained in going from 42 to 69-lb. single-face liners. As the single-face liner increases in weight its compression resistance – e.g., ring crush – increases and it behaves as a more rigid anvil. Because it does not deform as readily, greater stresses are developed in the double-face liner and more cracking results.

The effect of medium flat crush on combined board cracking is illustrated in Fig. 2. Rather unexpectedly, it was found that more cracking seemed to be obtained with the lower flat crush mediums. In general, it was thought that the higher flat crush mediums would resist crushing in the final stages of folding to a greater extent - thus imposing higher lateral forces on the double-face liner and inducing higher longitudinal tensions. However, the data fail to support this viewpoint.

TABLE III

EFFECT OF SINGLE-FACE LINER WEIGHT AND MEDIUM STIFFNESS ON COMBINED BOARD CRACKING

Liner Wt., lb./M ft.^{2}		Medium Flat Crush, p.s.i.	Combined Board Cracking, %		
D.F.	S.F.		10% R.H.	20% R.H.	30% R.H.
90	90	27.9	59.8	46.1	12.4
		31.4	38.0	15.5	6.5
		38.6	26.5	14.5	5.5
		50.4	26.4	7.2	3.9
90	69	29.4	35.8	4.5	4.5
		30.3	28.0	14.5	4.6
		39.8	15.4	13.2	1.4
		52.4	14.4	11.8	1.0
90	42	30.7	30.0	18.8	2.2
		31.1	22.6	11.9	6.9
		39.2	31.1	5.4	1.1
		58.5	13.4	2.0	0.9
69	90	30.6	29.5	24.6	3.9
		31.3	13.7	9.1	1.5
		39.4	4.8	1.8	0.8
		54.5	5.7	0.9	1.0
69	69	30.0	6.3	1.6	0.2
		31.0	2.3	0.2	0.0
		39.1	1.9	0.8	0.0
		55.5	0.5	0.0	0.0
69	42	28.6	4.7	4.1	1.1
		31.7	9.2	2.4	0.2
		37.7	2.5	0.3	0.2
		56.4	0.2	0.3	0.0

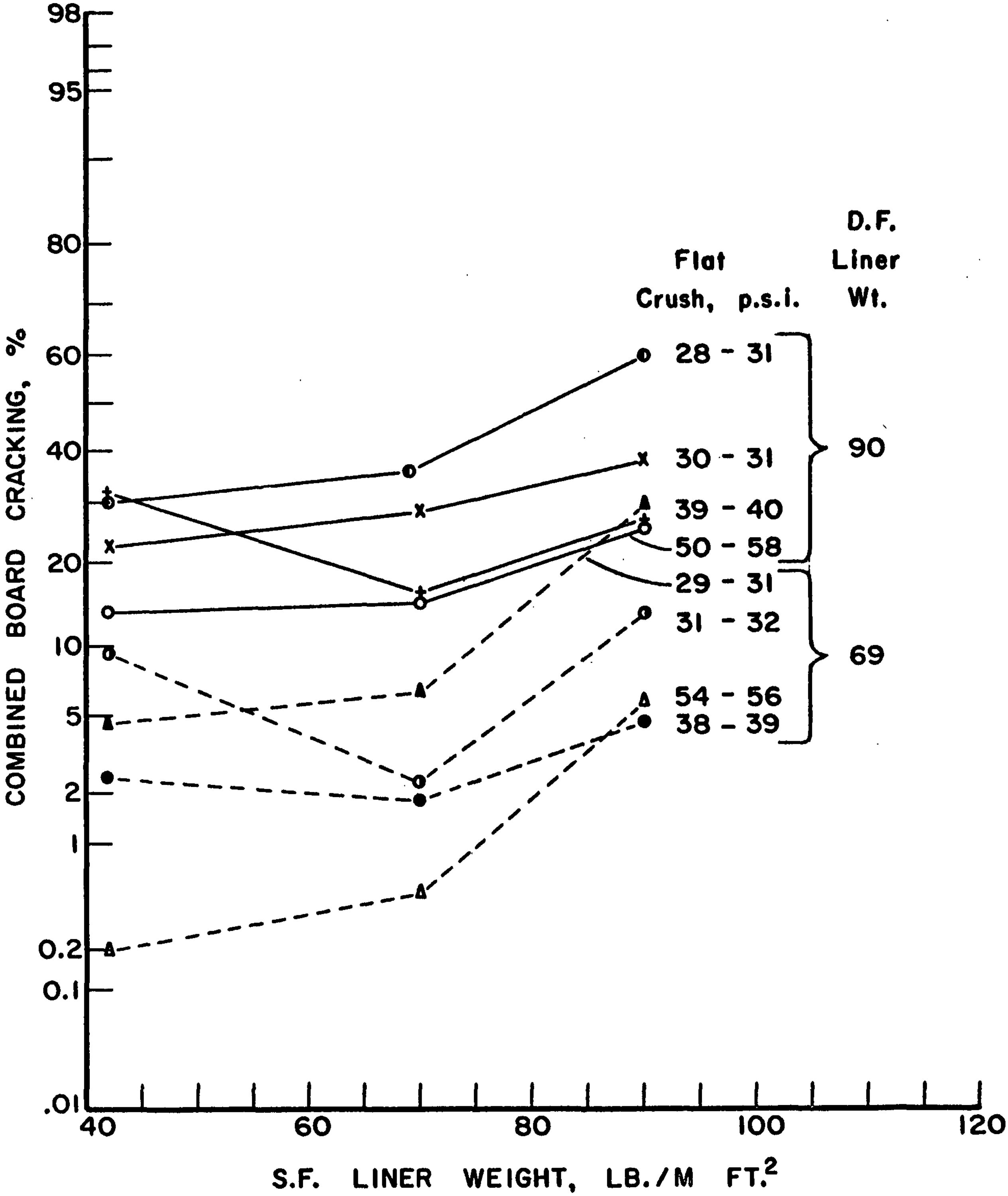

Figure 1. Effect of Single-Face Liner Weight on Combined Board Cracking at 10% R. H.

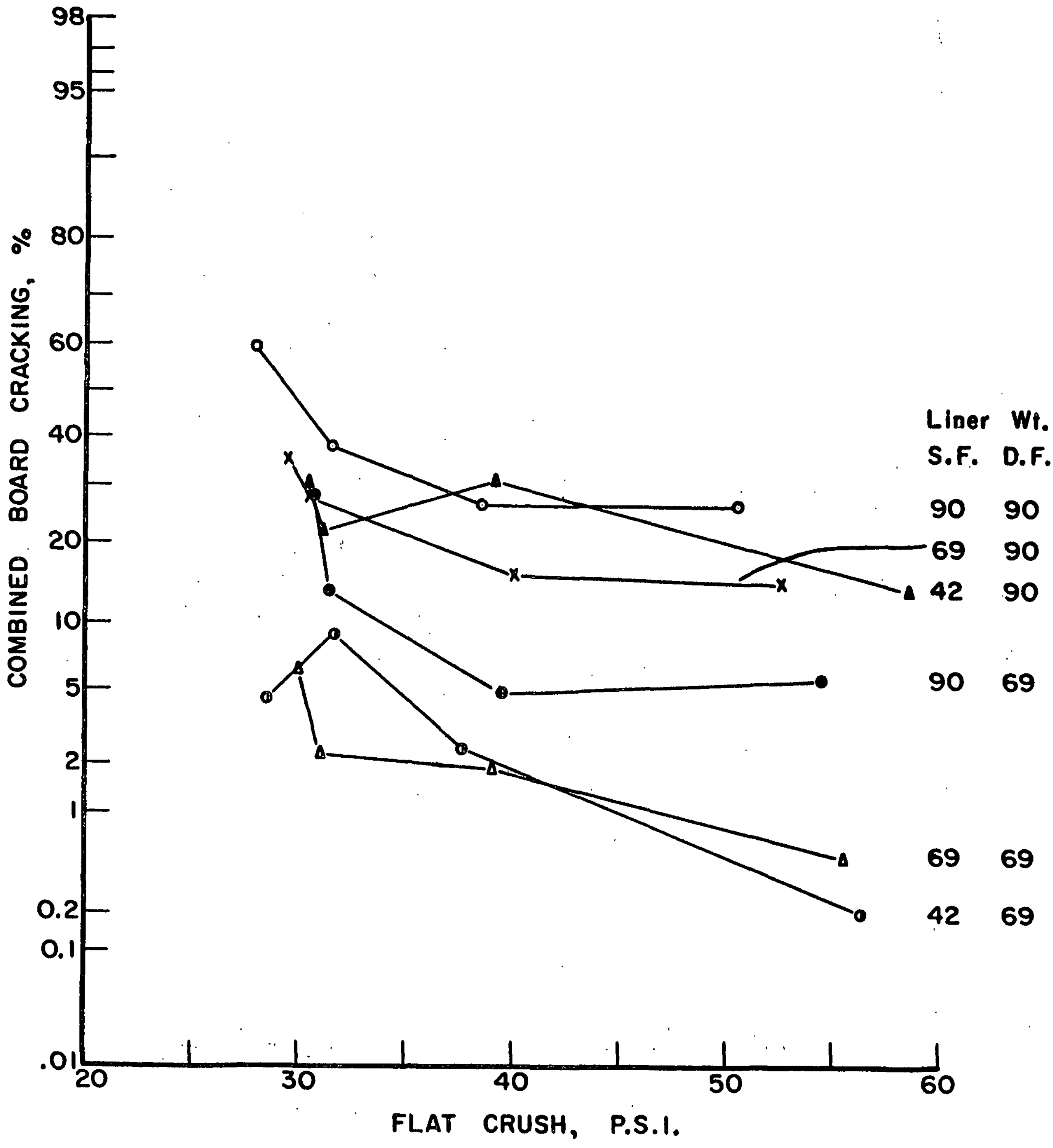

Figure 2. Effect of Medium Stiffness on Combined Board Cracking at 10% R. H.

As an alternative hypothesis, it was noted that smaller radii of curvatures seemed to be obtained with the lower flat crush mediums. This is illustrated in Fig. 3 where the "sharper point" obtained with the lowest flat crush medium is quite evident. In general, the smaller the curvature, the greater will be the tensile strains in the outer fibers and the more likely is cracking to occur.

While the above reasoning appears to explain the greater occurrence of cracking at lower flat crush, additional studies to confirm the data trends would be desirable.

B. Effect of coating on physical characteristics of kraft paper.

When the linerboard cracking study was initiated, it was found desirable to increase crack visibility using a black paint. Limited trials indicated that a flat black spray paint made by the Rust Oleum Corp. was very effective for this purpose and, within the limits studied, the amount of coating was not critical — see Report Five. It was felt that the nonpolar vehicles in the paint would have little or no effect on the physical characteristics.

As used in past work, the paint was sprayed on the test area from a distance of about 12 inches so as to obtain complete coverage of the test area. The painted specimen was then dried for at least 24 hours at less than 35% R.H., reconditioned at 50% R.H. for at least 48 hours and then placed in the test atmosphere. The above procedure resulted in a rather thorough impregnation of the outer fibrous layers of the board and it was suspected that the physical characteristics in the painted zone might be altered.

To crudely check on the above, a lightweight 50-lb. sack kraft sample was prepared with various coating amounts and evaluated for tensile, stretch, Taber

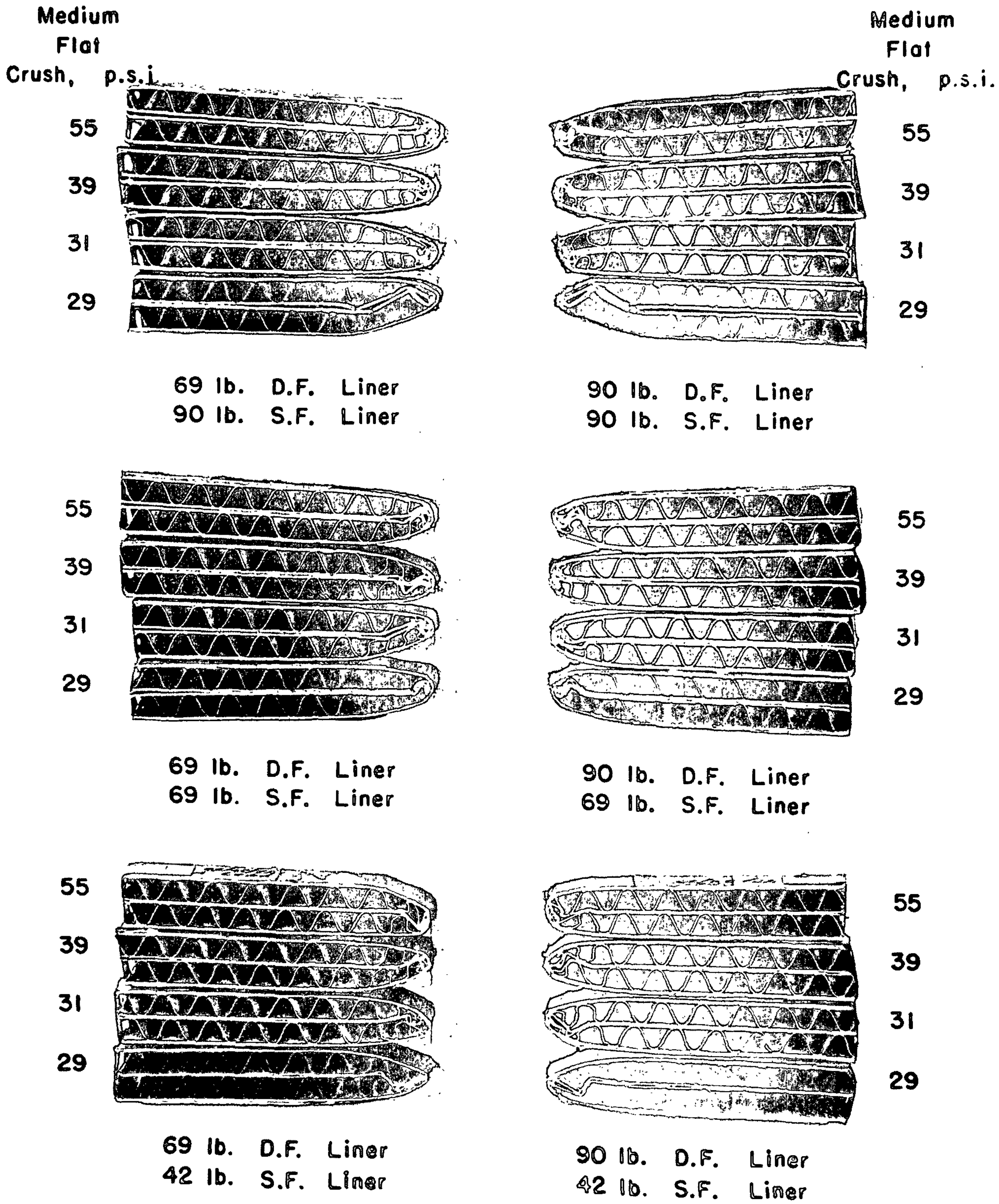

Figure 3. Appearance of Folded Specimens

stiffness, and porosity. It was felt that the use of the lightweight sheet would assist in detecting the possible effect of the coating. The results are summarized in Table IV.

TABLE IV

EFFECT OF BLACK PAINT ON THE PHYSICAL CHARACTERISTICS OF LIGHTWEIGHT KRAFT PAPER
(50-lb. sack paper)

			Rust-Oleum No. 412			
		0 Spray Pass (Control)	1 Spray Passes	2 Spray Passes	4 Spray Passes	Red Corrugating Ink No. 59NK2463
Tensile, lb./in.						
	In	26.8	34.9	36.6	34.8	30.6
	Cross	16.5	21.3	21.3	23.4	18.0
Stretch, %	In	1.40	1.71	1.73	1.60	1.64
	Cross	2.71	3.00	2.80	3.00	2.92
Taber stiffness, g.cm.						
	In	5.4	6.3	6.5	6.3	--
	Cross	3.1	3.7	3.7	3.6	--
Porosity, sec./100 cc.		8	25	51	320	--

As may be noted the "Rust-Oleum" paint markedly increased the tensile, stretch, Taber stiffness, and porosity of the kraft paper. Of these properties, the stretch is probably most critical because the folding process demands that the combined board fold through 180. These results suggested, therefore, that the paint coating could affect cracking results — particularly if two sheets exhibited different absorption characteristics. A limited trial with a red corrugating ink obtained from the Institute's Graphic Arts Department showed the same trend.

It was hypothesized that a portion of the effects noted above possibly occurred because of the long drying periods employed. To check this, tensile tests were performed after various periods of drying. The results are shown in Table V.

TABLE V

EFFECT OF COATING DRYING TIME ON TENSILE AND STRETCH
(50-lb. sack paper)

Drying Time, minutes	MD Tensile, lb./in.	MD Stretch, %
Rust Oleum No. 412		
0 (Control)	26.8	1.40
5	25.1	1.33
60	27.0	1.37
120	28.2	1.45
240	27.8	1.44
1440	34.9	1.71
Black Proving Ink No. 319B (nondrying)		
5	27.2	1.32
60	26.8	1.36

As may be noted the coatings had little or no effect on either the tensile or stretch for periods of time up to two or four hours after application. Thus, coating following by evaluation within a short period of time appears to be a possible avenue of approach.

The above findings are being rechecked using a (1) halftone ink (IPI Holdfast halftone black) supplied by the Institute's Graphic Arts Department and

(2) IPI Rotogem Black No. F51534. To apply a thin coat of the halftone ink, the ink is first rolled out on a sheet of plate glass. A stamp with a flexible rubber pad is then used to transfer ink from the glass to the board surface. The Rotogem Black ink is applied with a special roller applicator supplied by the ink manufacturer.

To summarize the above, the first series of tests suggested that the black paint coating could affect the board characteristics. The second series suggested that the effect would be minimized if the coating were not allowed to dry. This latter approach is now being pursued. In the meantime, an alternative approach using a dry carbon — carbon black "Witco No. 50" — appeared to be an alternative approach. The results obtained are discussed in the following section.

C. Correlation of linerboard cracking results (using carbon black to enhance crack visibility) with combined board cracking.

To test the use of carbon black to enhance crack visibility in the linerboard cracking test, a number of the 69 and 90-lb. liner samples were re-evaluated in the cracking tester. The carbon black was brushed over the test area using a brush with relatively stiff bristles and then gently wiped with a paper towel to avoid obtaining a too glossy surface. Gloss tended to be a problem, however, as the surface reflections made it more difficult for the operator to detect the onset of cracking.

The results obtained are summarized in Table VI where they may be compared with the combined board and liner results obtained previously using the black paint as a coating. As may be noted, cracking was detected at considerably

TABLE VI

COMPARISON OF LINER CRACKING RESULTS USING CARBON BLACK OR PAINT TO INCREASE CRACK VISIBILITY

Sample No.	Combined Board Cracking[a], % R.H. 10	Combined Board Cracking[a], % R.H. 30	Liner Cracking Angle, ° 10% R.H. Paint[a]	10% R.H. Carbon Black First Crack	10% R.H. Carbon Black Severe Crack	30% R.H. Paint[a]	30% R.H. Carbon Black First Crack	30% R.H. Carbon Black Severe Crack
			90-lb. Kraft - Untreated					
2420	77.4	21.2	45.4	32.4	39.1	57.6	49.2	59.5
2451	31.1	1.4	51.6	35.3	44.4	71.7	52.3	63.9
2464	99.9	81.5	45.4	32.5	39.6	60.0	42.6	53.1
2465	84.4	26.1	42.9	30.1	37.6	59.2	38.5	48.4
2491	53.0	4.8	51.1	31.8	40.2	72.2	38.9	51.2
			After High Humidity Relaxation					
2420	78.3	11.0	48.4	37.5	45.1	64.1	40.9	51.9
2464	99.9	81.0	44.2	39.7	48.3	66.7	44.9	56.0
2465	81.6	21.9	43.6	34.5	40.8	63.5	40.3	50.6
2491	47.1	5.4	52.2	37.8	46.2	72.9	46.1	55.7
			After Drying at 125°C. for 36 Hours					
2451	96.0	51.9	41.1	31.6	39.6	57.9	45.4	57.1
2491	96.4	44.3	44.3	30.9	37.8	57.0	44.1	56.4
			69-lb. Kraft - Untreated					
2413	34.4	2.3	54.5	43.3	51.2	64.3	47.9	59.0
2419	31.0	1.2	51.2	40.2	49.2	62.4	42.8	54.2
2426	23.3	0.6	51.4	42.2	50.6	64.6	43.8	55.0
2446	61.5	4.2	48.3	40.7	49.1	59.7	43.8	54.3
2463	41.4	2.2	49.2	42.3	51.0	59.8	44.6	54.8
2489	79.2	10.9	46.5	40.7	49.3	57.4	37.7	48.3
			After High Humidity Relaxation					
2413	44.2	0.7	53.1	46.6	56.4	64.9	52.7	65.4
2419	30.4	0.9	54.4	47.4	55.7	66.8	48.4	59.2
2426	29.3	0.3	55.9	46.7	55.4	69.3	51.8	61.5
2446	53.8	2.7	49.8	42.6	51.5	62.8	46.5	56.9
2463	63.4	0.4	51.9	41.0	49.9	67.8	49.4	59.5
2489	82.8	6.6	50.8	43.2	50.9	61.8	40.9	51.0
			After Drying at 125°C. for 36 Hours					
2413	87.4	14.4	47.2	42.2	50.8	57.6	43.4	55.2
2419	66.6	8.0	48.0	38.0	45.7	56.1	38.7	49.6
2426	66.6	5.4	47.7	38.7	47.3	56.7	40.9	51.8
2446	94.3	49.2	42.1	36.1	43.1	52.7	41.4	50.4
2463	84.8	6.0	46.3	34.7	43.0	55.8	47.0	54.7
2489	98.1	36.3	40.1	32.4	39.5	51.6	42.6	52.3

[a]Taken from Reports Two and Three, September 12 and November 19, 1963.

lower angles than in past work using the paint coating. The results using carbon black, however, did not correlate as well with combined board cracking. This is shown in Table VII.

TABLE VII

CORRELATIONS WITH COMBINED BOARD CRACKING

	90-lb. Liners		69-lb. Liners	
	N	Correlation Coefficient	N	Correlation Coefficient
Rust-Oleum No. 412	22	-0.70	36	-0.94
Carbon black				
First crack	22	-0.50	36	-0.70
Visible crack	22	-0.52	36	-0.79

On the basis of these results the carbon black appeared inferior to the paint coating and it was abandoned in favor of further trials with inks.

D. Effect of hardwood content on cracking

To assist the linerboard cracking research study, the Union Bag-Camp Paper Corporation kindly submitted four samples of 90-lb. laminated linerboard. These samples were made with the following percentages of hardwood in the furnish of the top sheet.

1. 15%
2. 15%
3. 60%
4. 60%

The above materials were evaluated in the linerboard cracking tester with the results shown in Table VIII. As may be noted considerably lower cracking angles were obtained with the higher hardwood percentages. Thus, it would be expected that combined board made with the "high hardwood" liner as the double-facer would exhibit considerably more cracking than would board made with the "low hardwood" liners.

TABLE VIII

EFFECT OF HARDWOOD CONTENT IN THE TOP SHEET OF A 90-LB. LAMINATED LINER ON LINERBOARD CRACKING

Per Cent Hardwood	Liner Cracking Angle, °			
	10% R.H.	20% R.H.	30% R.H.	50% R.H.
15	39.9	43.1	47.6	57.0
15	39.8	43.9	50.1	59.0
60	34.7	38.9	44.0	50.1
60	37.3	41.6	44.8	51.7

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

LINERBOARD CRACKING: EFFECT OF COATING DRYING TIME ON LINERBOARD CRACKING RESULTS

Project 1108-29

Report Eight

A Preliminary Report

to

TECHNICAL DIVISION
FOURDRINIER KRAFT BOARD INSTITUTE, INC.

April 6, 1965

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

LINERBOARD CRACKING: EFFECT OF COATING DRYING TIME ON LINERBOARD CRACKING RESULTS

SUMMARY

In the previous report a limited study was carried out which suggested that the black paint (Rust-Oleum no. 412) used in all previous work to facilitate crack detection changed the tensile and stretch of the sheet surface. The effect seemed most pronounced during the later stages of drying, i.e., after 1 day. To investigate this effect further, sheets were coated and evaluated for liner cracking angle after drying intervals of 15, 30, 60, 120, and 1440 minutes. Two coating systems were used, namely: (1) Rust-Oleum Black Spray paint no. 412 as used in previous work, and (2) IPI Rotocel Black F51-538. This ink was selected because of its flat dull appearance. (Note: A glossy finish made it more difficult to detect cracking.) In general, the results indicated that:

1. The cracking angle was more constant as the drying time increased when the Rust-Oleum spray paint was used. However, a decrease of about 3° in cracking angle was obtained in going from 15 to 1440 minutes drying time. When the Rotocel ink was used, the results passed through a minimum near 30 to 60 minutes of drying.
2. In terms of variability, the coefficient of variation was not affected by the type of coating or the drying time.
3. A few rechecks using the Rotocel ink exhibited poor reproducibility. Good reproducibility was obtained using the spray paint – particularly after 1-day drying. Except in two comparisons, equally good reproducibility was obtained at the 15-minute interval with Rust-Oleum spray paint.
4. The results suggest there is little advantage in the use of the Rotocel ink used. It is proposed to do additional work

with the Rust-Oleum paint system to further develop the feasibility of using short drying periods as the shorter periods could be helpful in using the test for control purposes.

The above is primarily concerned with methodology. In the near future it is anticipated that a series of experimental papers can be produced to explore the effect of various sheet and fiber variables on cracking.

INTRODUCTION

In Report Seven a limited investigation of the effect of the Rust-Oleum black paint coating which was used in past work to enhance crack visibility was initiated. In general, the results suggested that:

1. The tensile and stretch of the sheet were increased if the black paint coating was allowed to dry.
2. Little or no change in tensile or stretch appeared to occur in the first two to four hours after application.

Thus, coating followed by evaluation within relatively short periods of time appeared to be a possible avenue of approach.

This approach is being investigated using two coating systems, namely, (1) Rust-Oleum spray paint no. 412, and (2) IPI Rotocel ink no. F51-538. The ink was selected because of its flat dull finish as glossy surfaces make it difficult to detect cracking. Initial results obtained are discussed.

Two alternative approaches which could have the virtue of reducing the subjective judgment of the operator are also being considered. The first approach would involve measuring the torque required to fold the specimen. Hopefully, the maximum torque would coincide with the occurrence of cracking and the angle at which the peak torque occurred would correlate with combined board cracking.

In the second approach, a conductive coating would be deposited in the fold area in a sawtooth design. An electrical resistance meter could then be used to detect the occurrence of a crack in the surface sufficiently large to interrupt the coating.

In addition to the above, it is planned to initiate a study directed toward determining ways of modifying board to reduce cracking. For this phase the Institute's web former will be used to produce the experimental boards.

MATERIALS

Three 69 and three 90-lb. liners used in past work were selected for this phase. The liner cracking angles obtained in Reports Two and Three, together with the combined board cracking results, are shown in Table I.

TABLE I

CRACKING CHARACTERISTICS OF LINERS[c]

Test	R.H., %	69-Lb. Liners 2413	69-Lb. Liners 2426	69-Lb. Liners 2463	90-Lb. Liners 2420	90-Lb. Liners 2465	90-Lb. Liners 2491
Combined board cracking[b], %	10	34.4	23.3	41.4	77.4	84.4	53.0
	20	10.7	9.8	13.8	53.5	69.7	25.6
	30	2.3	0.6	2.2	21.2	26.1	4.8
	40	0.0	0.1	0.0	1.7	2.7	0.1
	50	0.0	0.0	0.0	1.0	2.2	0.3
Average[a]		(15.8)	(11.2)	(19.1)	(50.7)	(60.1)	(27.8)
Liner cracking angle[b], degrees[a]	10	54.5	51.4	49.2	45.4	42.9	51.1
	20	58.1	59.0	55.0	51.6	50.2	61.5
	30	64.3	64.6	59.8	57.6	59.2	72.2
	40	67.3	70.4	65.5	71.2	62.6	73.7
	50	85.7	82.9	79.3	67.2	65.2	80.5

[a] Based on 10, 20, and 30% results.
[b] Taken from Reports Two and Three, Project 1108-29 dated September 12, 1963 and November 19, 1963, respectively.
[c] Both the liner cracking angles and the degree of combined-board cracking were determined using Rust-Oleum black paint no. 412 as the coating.

CONDITIONING

The samples were conditioned at least 48 hours at 20% R.H. and 73°F. prior to test.

PROCEDURES

The six samples were evaluated using the following drying times after coating: 15, 30, 60, 120, and 1440 minutes. The Rust-Oleum spray paint no. 412 was applied by holding the container about 12 inches from the board surface and moving it slowly along the length of score. A special roller applicator supplied by the ink manufacturer was used to apply a thin coating of the Rotocel black ink.

In addition to the above, tests were also run using no coating of either type.

DISCUSSION OF RESULTS

The results obtained in this study of drying time effects are shown in Table II. Referring to the results, it may be noted that with the Rotocel ink the linerboard cracking angles tended to pass through a minimum near 30 to 60 minutes. The cracking angles at 15 minutes using the Rotocel ink were about equal to those obtained after drying for one day. The coefficients of variation — per cent standard deviation — were about equal throughout the range of drying times studied indicating that the drying time had little or no effect on the variability of the cracking angle.

During the course of the work, it was thought desirable to recheck the Rotocel results for Lot no. 2463 and the 60-minute results for the 90-lb. liner samples. Poor agreement between the original and recheck results was obtained.

TABLE II

EFFECT OF COATING DRYING TIME ON LINERBOARD CRACKING TESTER RESULTS

Sample No.	Average Combined Board Cracking, %[c]	No Coating				Linerboard Cracking Angle, °																			
		Angle to First Crack		Angle to Severe Crack		Angle to First Crack[a,b]										Angle to Severe Crack[a,b]									
						15 Min.		30 Min.		60 Min.		120 Min.		1440 Min.		15 Min.		30 Min.		60 Min.		120 Min.		1440 Min.	
		Av.	v.	Av.	v.	Av.	v.	Av.	v.	Av.	v.	Av.	v.	Av.	v.	Av.	v.	Av.	v.	Av.	v.	Av.	v.	Av.	v.
Rotocel Ink – 69-lb. Liners																									
2413	15.8	62.1	3.3	77.6	6.5	54.9	3.6	45.8	1.0	45.2	2.0	45.7	1.6	56.8	7.6	63.3	3.1	55.2	1.9	55.5	2.6	55.8	4.3	65.9	7.7
2426	11.2	59.8	2.3	71.2	2.4	49.9	2.7	44.8	2.4	46.0	9.0	46.5	1.3	48.9	2.4	59.3	3.1	54.1	4.6	53.5	9.1	56.7	7.3	58.3	2.8
2463	19.1	60.6	3.5	71.5	2.5	46.7	4.7	44.0	2.5	52.0	3.6	50.8	3.2	48.6	4.7	56.1	3.7	53.0	4.3	61.0	3.6	61.2	5.5	58.2	4.5
2463 Recheck						59.0		55.2		53.0		48.7		51.5		68.0		63.7		62.1		58.4		60.6	
Rotocel Ink – 90-lb. Liners																									
2420	50.7	58.3	4.6	69.0	3.1	46.6	2.9	46.2	5.0	40.8(48.6)	2.8	46.3	3.8	46.8	4.5	54.8	1.1	54.6	4.7	48.6	2.9	54.0	3.9	54.4	1.9
2465	60.1	57.0	4.1	67.5	2.8	46.1	8.3	42.7	4.8	40.3(43.2)	2.6	47.6	7.0	47.1	4.4	54.4	3.7	51.9	3.8	49.9	2.0	55.1	6.8	53.2	2.7
2491	27.8	61.4	3.2	72.7	1.9	53.8	6.7	42.3	9.3	41.1(46.6)	4.1	45.4	6.4	47.7	3.3	63.7	3.7	51.4	7.1	50.4	3.3	55.5	5.5	56.7	2.1
Av.[d]		59.9	3.5	71.6	3.4	49.7	4.8	44.3	4.2	44.3	4.0	47.0	3.9	49.3	4.5	58.6	3.1	53.4	4.4	53.2	3.9	56.5	5.6	57.8	3.6
Rust-Oleum Spray Paint – 69-lb. Liners																									
2413	15.8	57.6	4.1	66.8	4.9	55.5	3.0	53.4	4.6	63.8	3.9	59.6	4.3	54.2	3.7	66.1	2.3	62.6	2.0	72.2	4.5	69.3	4.3	61.8	3.0
2426	11.2	53.3	2.8	62.0	3.1	53.0	5.0	53.3	4.1	60.5	5.6	52.6	2.2	51.8	3.4	62.1	3.8	62.6	3.1	69.8	5.6	61.6	2.4	59.1	2.5
2463	19.1	57.3	4.5	66.7	4.8	59.1	5.2	58.1	6.2	61.2	3.7	53.7	6.1	53.4	4.4	68.6	4.7	68.1	5.5	70.4	4.8	63.3	3.9	61.4	3.4
Rust-Oleum Spray Paint – 90-lb. Liners																									
2420	50.7	49.9	6.1	59.0	6.0	47.7	3.6	50.5	4.7	52.0	5.5	48.4	6.3	45.6	3.3	56.2	3.8	59.6	4.0	60.4	5.3	56.3	6.5	51.9	4.1
2465	60.1	46.2	5.8	53.8	5.1	47.0	4.3	44.3	4.5	48.6	4.1	46.0	6.2	41.8	3.7	55.4	2.7	51.9	4.1	57.1	3.3	54.2	5.1	48.4	3.1
2491	27.8	48.7	5.9	57.8	4.9	51.8	3.4	50.3	4.9	57.3	8.6	55.1	2.8	48.0	6.5	61.7	3.2	59.9	4.1	66.1	6.4	63.9	3.9	54.2	7.7
Av.		52.2	4.9	61.0	4.8	52.4	3.4	51.6	4.8	57.2	5.2	52.6	4.6	49.1	4.2	61.7	4.2	60.8	3.8	66.0	5.0	61.4	4.4	56.1	4.0

[a]Value in parentheses is recheck.
[b]v = coefficient of variation.
[c]Average of 10, 20, and 30% R.H. results in Reports Two and Three.
[d]Based on original results.

More than a month intervened between original and recheck testing and slight differences in the specimen lighting arrangement may have occurred between the two testing times. More recently, it was observed that the bearings on the tester were exhibiting wear thus inducing "play" in the machine. However, this should not have produced a sudden shift in the results. Therefore, the cause of the relatively large differences is unknown. It is felt at this time that because of the poor reproducibility additional work with Rotocel ink F51-538 is not warranted.

Comparing the Rotocel results with the combined board cracking results obtained in 1963 using the Rust-Oleum spray paint, it may be noted that the 15-minute cracking angle results seem best related to the combined board cracking for the 90-lb. liners. For the 69-lb. liners, there seems to be no optimum time interval for a cracking angle-combined board cracking relationship. However, the differences in combined board cracking between samples were rather small.

Summing up for the Rotocel ink results, it appears that in so far as correlation with combined board cracking is concerned, the 15-minute time interval seems superior to the longer time intervals. In this time range, however, the cracking angle is decreasing with drying time and care would be required to control the time between application and test. Investigations at shorter intervals would be necessary to determine what a desirable time tolerance would be. However, in view of the poor reproducibility encountered in the recheck tests a considerable effort might be required to develop a standardized procedure. For these reasons no further work with the Rotocel ink is planned.

When the Rust-Oleum spray paint results are examined it may be noted that with the exception of the 60-minute results, the cracking angle was nearly constant with time — perhaps decreasing slightly at the 1-day time. (Later results indicate a decrease in "first crack" angles of about 3 degrees in going from 15 to 1440 minutes. The latter trend is surprising in view of the higher stretch obtained for 1-day drying in Report Seven. The variability (coefficient of variation) was about constant for all the times studied.

For the 90-lb. liners, the Rust-Oleum spray paint cracking angle results were qualitatively in agreement with the combined board cracking for all times except 30 minutes. For the 69-lb. liners the cracking angle results were less well related to the combined board cracking results — probably caused, in part, by the small differences in cracking behavior.

The cracking angles using Rust-Oleum spray paint differed from those obtained in 1963 (see Table I). The present test materials were sampled, of course, much deeper in the roll and this might account for a portion of the differences. To check reproducibility using spray paint a series of comparisons were made for the 15 and 1440-minute drying periods. The results are shown in Table III. In general, good agreement between rechecks was obtained for the 1440-minute drying period. At 15 minutes the agreement between trials was usually good but was marred in two trials by differences as large as 5 to 7 degrees.

The results in Table III also indicate a lowering of the cracking angle (to first crack) by from .4 to 4.8 degrees in going from 15-minute to 1-day drying periods. The differences in response of the boards to drying are probably due to sampling fluctuations but also could possibly represent interactions between coating and board.

Because of the relatively good reproducibility, further work with the Rust-Oleum spray paint seems justified. If satisfactory results can be obtained in future work with the shorter time intervals, the use of the tester in control work would be facilitated.

TABLE III

REPRODUCIBILITY OF CRACKING ANGLE RESULTS USING SPRAY PAINT

Sample No.	15-Minute Drying Time						1440-Minute Drying Time					
	Trial 1	Trial 2	Diff.[a]	Trial 3	Diff.[a]	Av.	Trial 1	Trial 2	Diff.[a]	Trial 3	Diff.[a]	Av.
	Angle to First Crack, °						Angle to First Crack, °					
2413	55.5	52.0	-3.5	55.6	+0.1	54.4	54.2	54.4	+0.2	53.5	-0.7	54.0
2426	53.0	53.8	+0.8	58.0	+5.0	54.7	51.8	53.1	+1.3	53.1	+1.3	52.7
2463	59.1	52.0	-7.1	57.3	-1.8	56.1	53.4	52.7	-0.7	52.0	-1.4	52.7
2420	47.7	50.2	+2.5	47.7	0.0	48.5	45.6	46.2	+0.6	45.7	+0.1	45.8
2465	47.0	46.5	-0.5	47.1	+0.1	46.9	41.8	41.9	+0.1	43.2	+1.4	42.3
2491	51.8	50.5	-1.3	51.4	-0.4	51.2	48.0	46.8	-1.2	47.4	-0.6	47.4
	Angle to Severe Crack, °						Angle to Severe Crack, °					
2413	66.1	63.2	-2.9	65.2	-0.9	64.8	61.8	62.6	+0.8	61.8	0.0	62.1
2426	62.1	63.8	+1.7	67.5	+5.4	64.5	59.1	61.6	+2.5	60.8	+1.7	60.5
2463	68.6	62.1	-6.5	66.5	-2.1	65.7	61.4	61.9	+0.5	60.8	-0.6	61.4
2420	56.2	59.7	+3.5	56.0	-0.2	57.3	51.9	52.6	+0.7	53.0	+1.1	52.5
2465	55.4	55.6	+0.2	54.7	-0.7	55.2	48.4	49.1	+0.7	50.8	+2.4	49.4
2491	61.7	60.6	-1.1	60.3	-1.4	60.9	54.2	53.8	-0.4	55.6	+1.4	54.5

[a] Based arbitrarily on Trial 1 results as reference.

For the results obtained with no coating, the variability seemed about equal to the variability in the trials with the ink or paint. However, a considerable shift in level occurred between the two trials. Better grazing angle illumination and proper magnification might reduce such discrepancies.

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

EFFECT OF SURFACE ADDITIVES AND OVERDRYING ON CRACKING

Project 1108-29

Report Nine

A Preliminary Report

to

TECHNICAL DIVISION
FOURDRINIER KRAFT BOARD INSTITUTE, INC.

July 20, 1965

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

EFFECT OF SURFACE ADDITIVES AND OVERDRYING ON CRACKING

SUMMARY

A limited investigation of the effects of two surface additives and of overdrying on the cracking potential of 90-lb. linerboard has been carried out as part of a study of the effects of various factors on board cracking.

As expected, a surface treatment of starch increased bonding strength and other properties, but lowered the cracking angle. Thus, a surface starch application resulted in an increased tendency to crack. It was hoped that surface treatment with a debonding agent would decrease the tendency to crack without materially lowering other properties. In these trials 0.5 and 2-1/2% additions of Hyamine had little or no effect on the liner cracking angle.

When 90-lb. board was dried to a low moisture content and then reconditioned, a substantial decrease in the cracking angle was obtained. Thus, the tendency to crack should be much greater after severe drying treatments. This is in agreement with earlier results involving prolonged heating at high temperatures.

INTRODUCTION

Past work has been directed primarily toward the development of a test device for evaluating the cracking characteristics of kraft liner. The development of the tester and a qualitative analysis of the strains developed in linerboard during folding is reviewed in Report Six. Later reports have been concerned with the development of better coating procedures to facilitate detection of cracking.

As another phase of the work, a limited study has been underway to develop information regarding the effect of various board manufacturing variables on cracking. The objective here would be to determine ways of modifying board so as to reduce cracking.

Based on present understanding of the folding phenomena, it appears that cracking will be reduced if the stretch on the outer board layers is increased. For example, board laminated with a high stretch outer facing was shown in early work to have superior characteristics. Surface applications which improve bonding seem to have an adverse effect on cracking for this reason. Other factors which should affect cracking are shear strength, ply bonding thickness, type of fiber, refining, etc. For example, in Report Seven a number of board samples made with low and high hardwood contents and made available by the Union Bag-Camp Paper Corporation were evaluated. As expected, high hardwood contents resulted in lower cracking angles and higher combined board cracking.

It was hoped that the Institute web former could be used to produce experimental sheets under a wide variety of conditions. Preliminary trials indicated, however, that satisfactory sheets in the heavier weights could not be produced.

Therefore, as an alternative it was decided to study the effects of overdrying and surface additives on commercial board. To study the effect of overdrying, a roll of 90-lb. kraft linerboard was fed through the Institute's coater. The effects of surface applications of starch and Hyamine were studied using the same linerboard sample.

PROCEDURES

DRYING

In this phase the board was fed through the drying section of the coater at a speed of 13-1/2 feet per min. The air driers were controlled at 400°F. For a control, board was fed through the machine with the driers off. The moisture content of the dried material was 0.65%.

SURFACE APPLICATIONS

A small laboratory size press was used to obtain 0.5 and 2-1/2% pick-ups of Hyamine 1622 — a debonding agent. Solution concentrations of 5 and 10% were used and 2 passes at 15 p.s.i. pressure were made.

The same press was used to obtain 1 and 2% pick-ups of starch (Superfilm 40).

Control samples were taken using 1 pass with no coating and 1 pass with plain water.

The materials were drum dried after coating.

TESTING

All materials were conditioned at 20% R.H. and 73°F. and all testing was carried out in this atmosphere.

DISCUSSION OF RESULTS

The results obtained are summarized in Table I. As would be expected, overdrying lowered the cracking angle substantially. Thus, it would be anticipated that the overdried board would exhibit greater cracking when used as a double-face liner on corrugated board. With regard to other properties the dried material exhibited somewhat higher ring compression tensile and IGT bonding strength.

Hyamine normally acts as a debonding agent. It was thought a light surface application to the board would reduce the bonding in the surface layers. This would result in better cracking performance without any major change in other properties. In this case, however, little or no change in cracking angle occurred. The Hyamine did reduce bonding strength slightly and increase stretch. Some improvement in the liner cracking angle would have been expected under these circumstances.

Lower cracking angles tended to be obtained when starch was used as a surface treatment. Thus, more combined board cracking would be expected. The starch treatment increased bonding strength, tensile, and ring compression as would be expected.

TABLE I

EFFECT OF DRYING AND SURFACE ADDITIVES ON LINER CRACKING AND OTHER CHARACTERISTICS

Treatment	Cracking Angle, degree	Moisture Content, %	Weight, lb./M ft.^{2}	Caliper, pt.	IGT Bonding Strength, kp. cm./sec.	Tensile M.D.	lb./in. C.D.	Stretch, % M.D.	Stretch, % C.D.	Modified Ring Compression, lb./in.
Drying Study										
Control	49.2	4.8	88.1	23.7	117	159.6	82.2	1.6	2.8	36.7
Dried	43.4	3.5	87.8	23.4	126	174.5	84.6	1.5	2.4	38.7
Surface Application										
Control – dry	46.3	--	88.6	23.4	107	161.7	79.3	1.4	2.5	36.5
Control – water	45.0	--	87.3	23.6	123	159.8	81.4	1.4	2.6	35.1
0.5% Hyamine	46.9	--	88.1	25.1	91	160.9	81.3	1.6	2.6	36.3
2-1/2% Hyamine	44.3	--	89.9	25.5	97	157.0	81.8	1.6	3.0	36.3
1% Starch	44.4	--	88.7	24.3	184	174.0	85.8	1.6	2.7	39.4
2% Starch	42.8	--	89.6	24.0	258	176.4	89.0	1.6	2.7	40.4

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